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Proceedings EIGHTEENTH VERTEBRATE PEST CONFERENCE [complete]

Proceedings

EIGHTEENTH

VERTEBRATE PEST CONFERENCE

March 2-5, 1998
Costa Mesa, California

Includes the following peer reviewed articles:

POPULATION DYNAMICS: THE FOUNDATION OF WILDLIFE DAMAGE MANAGEMENT FOR THE 21ST CENTURY by Richard A. Dolbeer

TRACING THE HISTORY OF BLACKBIRD RESEARCH THROUGH AN INDUSTRY'S LOOKING GLASS: THE SUNFLOWER MAGAZINE by George M. Linz and H. Jeffery Homan

MANIPULATING HABITAT QUALITY TO MANAGE VERTEBRATE PESTS by Dirk Van Vuren

Proceedings

EIGHTEENTH VERTEBRATE PEST CONFERENCE

DoubleTree Hotel

Costa Mesa, California

March 2-5, 1998

Arranged by the

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Editors

REX O. BAKER and A. CHARLES CRABB

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The conference is made possible by the efforts of many people who work for the most part behind the scene and often receive little or no recognition for their contributions. The Council, Executive Board, and Conference Committee Chairpersons wish to extend special acknowledgment and thanks to the following individuals:

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*Paper was peer reviewed prior to publication.
**Paper was accepted by the Vertebrate Pest Council for publication although not presented.

Editors' note: In the preparation of the proceedings, editorial liberties were taken on very few papers. For the most part, papers appear as originally written except for instances where minor changes were made for the sake of clarity and uniformity of style.

OPENING REMARKS—EIGHTEENTH VERTEBRATE PEST CONFERENCE

REX O. BAKER, Horticulture/Plant & Soil Science Department, California State Polytechnic University, Pomona, California 91768.

Proc. 18th Vertebr. Pest Conf. (R.O. Baker & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 1998.

On behalf of the Vertebrate Pest Council, welcome to the Eighteenth Vertebrate Pest Conference. For 36 years, the Council has been presenting these conferences for the purpose of advancing knowledge in the field of vertebrate pest management. The conference proceedings are utilized extensively throughout the world as a source of information regarding vertebrate pest biology, behavior, ecology, and integrated pest management technology.

Never before has the vertebrate pest management field been under as much pressure to change from using traditional control methods of trapping and toxicants, to what are viewed as more humane and environmentally friendly methods. Unfortunately, the general public is being led to believe that very cruel pest management methods are utilized and that even some pest animals are cuddly creatures that have the same rights as humans. Agreed, vertebrate pests should be treated humanely, but treated as if they belong everywhere even when causing damage to man, his livestock, pets, endangered species, and the environment? Citizens are ill informed of how cruel nature is in the struggle for survival, or how advanced the animal damage management field is in the use of integrated pest management methods and the use of humane control techniques.

One of our primary objectives as vertebrate pest managers must be to change our image through public education and our appearance, while continuing to learn more about new integrated pest management methods. "I challenge you to maintain a more professional image for your entire organization." Your dress, equipment, manner of solving vertebrate pest problems, and, yes, your customer and public relations must always be a high priority.

I am sure the program Paul Gorenzel and Desley Whisson have arranged will help us in meeting society's challenges towards developing better integrated vertebrate pest management programs and improving our image. I would like to thank and recognize the following conference committee chairs, council members, and volunteers for the extensive work they have done in putting on this conference: Paul Gorenzel and Desley Whisson, Program Chairs; Sydni Gillette, Registration; Charles Crabb and Gerry Miller, Arrangements Co-Chairs; Charles Crabb, also Proceedings Editor; Minoo Madon, Field Trip Chair; Gregory Giusti, Chair, and Robert Timm, Assistant Chair, Commercial Displays; Terry Salmon, Chair-Elect and Continuing Education Chair; and Gary Simmons, Publicity Chair.

One of the most valuable experiences enjoyed at the conference is the opportunity to meet and chat with fellow associates, many of whom are leading experts in the vertebrate pest management field. A tremendous exchange of information takes place in the commercial display room and at the evening socials. Take good advantage of these opportunities, and do not be shy.

A big thanks also to the speakers and session chairs—many have traveled long distances and all have put a lot of long hours into their presentations.

One of the most active foreign speakers in the past was Peter Nelson of New Zealand. Unfortunately, Peter passed away in January. His valuable knowledge, warm open heart, and great sense of humor will be missed. He will always be in our fond memories.

The National Animal Damage Control Association (NADCA) will be meeting during the conference. The NADCA newsletter is another great resource for technical information. If you are not a member yet, join!

Please complete the evaluation survey so that future conferences can be improved, and so that you can enjoy Wednesday night's commercial forum and hosted buffet.

Enjoy the conference!

POPULATION DYNAMICS: THE FOUNDATION OF WILDLIFE DAMAGE MANAGEMENT FOR THE 21ST CENTURY

RICHARD A. DOLBEER, U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center, 6100 Columbus Avenue, Sandusky, Ohio 44870.

ABSTRACT: To justify and defend lethal or reproductive control programs to solve vertebrate pest problems, wildlife biologists must have a sound understanding of the population status and dynamics of the problem species. Models are essential to project how populations will respond to proposed management actions, providing a scientific foundation to counter the emotional debates that often arise. Four population models (PM1 to PM4) for predicting population responses are described. PM1 and PM2 explore the relative efficacy of reproductive and lethal control for vertebrate species over 10-year intervals. PM3 simulates population responses to actual management actions through 10-year intervals. PM4 simulates population changes for a species at weekly intervals over an annual cycle, exploring the immediate (≤ 1 year) impact of population management actions. Population simulations using PM1 and PM2 demonstrated that for most vertebrate pest species considered, lethal control will be more efficient than reproductive control in reducing population levels. Reproductive control is more efficient than lethal control only for some rodent and small bird species with high reproductive rates and low survival rates. A simulation (PM3) of the removal of 47,000 laughing gulls (*Larus atricilla*) from the Long Island-New Jersey population accurately predicted the 33% decline of the population over five years. A simulation (PM4) of the annual cycle of the common grackle (*Quiscalus quiscula*) population in the eastern United States demonstrated why removing 4.2 million birds in one winter had no discernible impact on subsequent breeding populations. Understanding the population dynamics of wildlife species is the cornerstone to successful management, and population models will be essential for this task in the years to come.

KEY WORDS: black rat, fruit bat, grackle, gull, lethal control, model, population dynamics, reproductive control, vertebrate pest

THIS PAPER HAS BEEN PEER REVIWED.

Proc. 18th Vertebr. Pest Conf. (R.O. Baker & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 1998.

INTRODUCTION

The world human population is increasing at an unprecedented rate of 90 million people/year (about 4 million/year in North America). In parallel, dramatic increases in populations of many wildlife species such as Canada geese (*Branta canadensis*), gulls (*Larus* spp.), white-tailed deer (*Odocoileus virginianus*), double-crested cormorants (*Phalacrocorax auritus*) and beaver (*Castor canadensis*) have occurred in North America over the past 30 years due to land-use changes and effective management programs by public and private agencies (e.g., Ankney 1996; Hatch 1995; Belant and Dolbeer 1993). These simultaneous population expansions inevitably lead to conflicts between wildlife and humans in an increasingly crowded world. Managing these conflicts is an intricate, difficult process because of four factors:

1) The science of wildlife management is complex, particularly understanding and predicting the behavior, population dynamics and economic/health impacts of wildlife species.

2) Wildlife biologists study and manage sentient, adaptable and secretive organisms, requiring the development of many complex, labor-intensive tools and techniques to census, monitor, and measure.

3) The sociological aspects of wildlife management are diverse and emotional, particularly the oftentimes polarized views of society regarding the killing and management of wildlife species.

4) The regulatory aspects of wildlife management can be almost overwhelming, particularly regarding the legal status of wildlife, National Environmental Policy Act (NEPA) processes, and the registration of chemicals as management tools.

The author believes that as a profession of research and management biologists, we have become so involved in techniques development, sociological issues and regulatory aspects related to wildlife management that we have lost focus on our most important mission: the science of wildlife management. Furthermore, the author contends that the foundation of wildlife management is understanding the population dynamics of the species in question. Any management action recommended should be based and clearly communicated on this foundation of population dynamics. Unfortunately, this is often not the case either because we fail to communicate our knowledge and understanding, or because we do not have the level of understanding needed.

There are many situations where lethal control has been implemented to resolve human conflicts with wildlife (e.g., Dolbeer 1986; Dolbeer et al. 1993, 1997; Bedard et al. 1995). However, our urbanized public generally advocates nonlethal means of managing problem populations of wildlife (Stout et al. 1997). To this end, there has been increased interest in the development of reproductive control strategies for wildlife species (Kirkpatrick and Turner 1985). To justify lethal or reproductive control programs to state and federal regulatory agencies and the public, wildlife biologists must have a sound understanding of the population status and dynamics of the problem species. Population models are essential to document the immediate impact that lethal or reproductive control programs will have on local, regional and continental populations and to project how populations will respond to these management actions. Such models provide a scientific foundation for management actions to counter the emotional debates that often arise.

The author's objective is to focus on this foundation of population dynamics from which, in his opinion, our profession has drifted. Four population models for vertebrate species developed on Excel spreadsheets are described. Second, these models are used to demonstrate fundamental principles of population dynamics for several species that often conflict with human activities. Finally, two examples are given of how these models and the underlying principles demonstrated have provided guidance and justification for management actions to reduce conflicts.

METHODS

Population Models 1 (PM1) and 2 (PM2)

PM1 explores the relative efficacy of reproductive and lethal control for vertebrate species that produce ≤1 generation per year (i.e., offspring do not reproduce until ≥1 year old). PM1 also determines reproductive and survival parameter values needed to produce a stable population and provides an estimate of the age composition. PM1 has six age classes (0 [year of birth], 1, 2, 3, 4, and 5+ year-old animals). Population parameters that must be entered are initial estimates of the age distribution and survival and reproductive rates by age class (Table 1, Figure 1). PM1 is designed to simulate population levels by age class for 20 years, the first 10 in a stabilizing or "baseline" mode and the next 10 in a "treatment" mode that shows population response to various management actions. No compensatory factors (e.g., increased annual survival rates during a period of management-induced population decline) are included in PM1. PM1 simply is designed to determine parameter values for species that result in stable populations and to compare the relative efficacy of control strategies within and among species.

To simulate population responses of a species, the best available mean values from the literature or other sources are input for the population parameters. An initial age structure is also entered, arbitrarily using 200 to 400 individuals for age-class 0 and then reasonable approximations for the remaining age classes (e.g., 90 for age-class 1, if the mean annual survival rate of 200 age-class 0 animals is estimated to be about 0.45). If these initial parameter estimates cause the population to increase (decrease), the reproductive and/or survival rates are adjusted downward (upward) until the population stabilizes by year 10 (Table 2). Parameter values that result in a stable population should represent realistic values for a typical population of the species. In year 11 (Baseline 1,000), the stable age structure from year 10 is adjusted to sum to 1,000 individuals for age classes 0 to 5+ (Figure 1). This simply provides a convenient baseline number for the stable population (1,000) to compare with population levels during the 10-year treatment period.

In treatment years 1 to 10, parameter values are adjusted to reflect the simulated management action. For example, one may want to compare the relative response of the population over 10 years to a 50% decrease in the survival rate of adult animals versus a 50% decrease in the reproductive rate. The model is first run with the survival rate reduced and then with the reproductive rate reduced (Figure 1). These simulations provide simple but fundamental insights into the sensitivity of a species, given its population characteristics, to reproductive versus lethal control.

PM2 is a derivation of PM1 for simulating populations of rodents that produce more than one generation per year (e.g., commensals). PM2 has two age classes (immature and mature) and allows three generations per year.

Population Model 3 (PM3)

PM3 has the same basic structure as PM1 with the addition that the stable population in baseline year 0 can be adjusted to an actual population level (e.g., 131,000 nesting laughing gulls in New Jersey-Long Island in 1989 [see below]) so that a real-world population can be simulated in treatment years 1 to 10. Then, actual numbers of animals or eggs removed by management actions are entered for each of the 10 treatment years. Finally, compensatory factors can be added to adjust reproductive and survival rates upward when populations decline below baseline (stable) levels as a result of management actions (Table 1). Thus, whereas PM1 and PM2 provide a generic comparison of population responses among species and management actions, PM3 allows simulation of a real-world situation. An added bonus is that PM3 provides an estimate of the total population (non-breeding and breeding animals) when census data are available for only the breeding population (e.g., as in most colonial waterbird populations; Belant and Dolbeer 1993).

Population Model 4 (PM4)

Whereas PM1-3 simulate changes in populations at yearly intervals, PM4 simulates population changes at weekly intervals over an annual cycle. PM4 explores the immediate (≤1 year) impact of population management actions. The population is initialized (week 0 = April 23) using actual population estimates for the species to be simulated and stable age composition, reproductive and survival estimates determined from PM1. Also, the start and end weeks for fledging/weaning are entered so that young (age 0) enter the population during appropriate weeks. The population is then simulated for 52 weeks (May 1 to May 1) and parameters adjusted if needed to produce a population that is stable. For the treatment simulation, start and end weeks for removal are entered as well as the number of animals to be removed. As with PM3, a compensatory factor for survival can be added to adjust weekly survival rates upward (downward) as the population declines below (exceeds) the baseline population for a given week.

RESULTS

Population Responses to Lethal and Reproductive Control (PM1, PM2)

The Republic of Maldives, an archipelago nation in the Indian Ocean, has two mammals species, the endemic giant fruit bat (*Pteropus giganteus*) and introduced black rat (*Rattus rattus*) that damage agricultural crops (Dolbeer et al. 1988). These two species have dramatically

This paper has been peer reviewed.

Table 1. Population parameters used in Models 1 to 4.

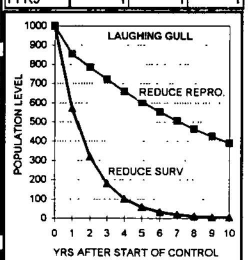
Population Parameter	Definition
JSR[a]	Juvenile (age 0 [weaning/fledging] to age 1) survival rate.
ASR[a]	Adult (≥age 1) survival rate (annual).
ESR[a]	Egg survival rate (egg laying to fledging/weaning).
EPRA[a]	Eggs per reproducing adult/per.
FFR1...5[a]	Fraction of females reproducing in age classes 1...5.
MCF[b]	Maximum compensation factor to adjust ASR, JSR, and ESR; = 1/ASR.
CF[b]	Compensation factor for ASR, JSR, and ESR; = MCF-((MCF-1)*FIPR).
FIPR[b]	Fraction of initial (baseline) population remaining.

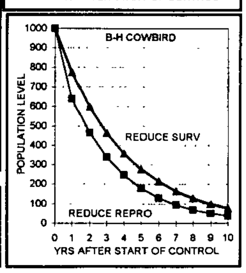
[a]Used in Population Models 1 to 4.
[b]Used in Population Models 3 and 4.

SPECIES: LAUGHING GULL
SIMULATION: DECREASE ADULT SURVIVAL BY 50%/DECREASE ADULT REPRODUCTION BY 50%

PERIOD	YR	AGE 5+	AGE 4	AGE 3	AGE 2	AGE 1	AGE 0	TOTAL POP
Initial		200	60	80	110	120	360	930
Stabilizing	1	208	64	88	96	173	236	864
Stabilizing	2	218	70	77	138	113	246	862
Stabilizing	3	230	61	111	90	118	260	871
Stabilizing	4	233	88	72	95	125	256	870
Stabilizing	5	258	58	76	100	123	255	869
Stabilizing	6	252	61	80	98	123	256	870
Stabilizing	7	250	64	79	98	123	256	870
Stabilizing	8	251	63	78	98	123	256	870
Stabilizing	9	252	63	79	98	123	256	870
Stabilizing	10	251	63	79	98	123	256	870
Base1000	0	289	72	90	113	141	294	1000
Treatment 1	1	289	72	90	113	141	147	853
Treatment 1	2	289	72	90	113	71	147	782
Treatment 1	3	289	72	90	56	71	142	720
Treatment 1	4	289	72	45	56	68	128	659
Treatment 1	5	289	36	45	54	61	117	603
Treatment 1	6	260	36	44	49	56	107	552
Treatment 1	7	237	35	39	45	51	98	506
Treatment 1	8	217	31	36	41	47	90	463
Treatment 1	9	199	29	33	38	43	82	424
Treatment 1	10	182	26	30	35	40	75	388
Base1000	0	289	72	90	113	141	294	1000
Treatment 2	1	145	36	45	57	141	147	571
Treatment 2	2	72	18	23	56	71	79	319
Treatment 2	3	36	9	23	28	38	46	180
Treatment 2	4	18	9	11	15	22	26	102
Treatment 2	5	11	5	6	9	12	15	57
Treatment 2	6	6	2	4	5	7	8	32
Treatment 2	7	3	1	2	3	4	5	18
Treatment 2	8	2	1	1	2	2	3	10
Treatment 2	9	1	0	1	1	1	1	6
Treatment 2	10	1	0	0	1	1	1	3

PARA-METERS	STABLE POP.	TRT 1 POP.	TRT 2 POP.
JSR	0.48	0.48	0.48
ASR	0.8	0.8	0.4
ESR	0.551	0.275	0.551
EPRA	1.1	1.1	1.1
FFR1	0	0	0
FFR2	0.3	0.3	0.3
FFR3	1	1	1
FFR4	1	1	1
FFR5	1	1	1





JSR	=JUVENILE SURVIVAL RATE (FLEDGE/WEAN TO AGE 1)
ASR	=ADULT (≥AGE 1) SURVIVAL RATE (ANNUAL)
ESR	=EGG SURVIVAL RATE (EGG LAYING TO FLEDGE/WEAN).
EPRA	=EGGS PER REPRODUCING ADULT.
FFR1. 5+	=FRACTION OF FEMALES BREEDING IN AGE CLASS 1 5+.

Figure 1. Example of tabular and graphic output from Model 1 in which: 1) parameters values were determined for laughing gulls to produce stable population (stabilizing years 1 to 10); and 2) population responses to 50% reductions in survival or reproduction were simulated for 10 years (Treatments 1 and 2). In addition, graphic output for same simulations with cowbirds (see Table 2 for parameter values) is presented.

different life histories (Table 2) which provide an informative comparison of population response to control strategies (Figure 2). Fruit bat populations, with low reproductive rates and high survival rates, can be reduced four to six times more efficiently by lethal compared to reproductive control applied for three years (Table 3). In contrast, rat populations, with high reproductive rates, can be reduced two to three times more efficiently by reproductive compared to lethal control. The validity of these simulated responses was supported by management actions in the Maldives. Lethal control suppressed populations of fruit bats by 46 to 70% one year later, whereas rat populations recovered fully (Dolbeer et al. 1988).

Brown-headed cowbirds (*Molothrus ater*) and laughing gulls are bird species with contrasting life histories (Table 2) that demonstrate these same differences in population response to control strategies (Figure 1). Laughing gull populations, with relatively low reproductive rates, can be reduced four to six times more efficiently over a three-year period by lethal compared to reproductive control (Table 3). Cowbird populations, with high reproductive rates, are more efficiently reduced by reproductive control when control is directed only at adult (≥ 1 year old) animals. When control can be directed at all age classes, lethal control is three times more efficient than reproductive control. Red-billed quelea (*Quelea quelea*) populations respond in a manner similar to cowbirds.

The predicted relative efficiencies of lethal and reproductive control for various vertebrate species (Table 3) can be generalized based on adult survival rate (ASR) and age at which animals reproduce (Figure 3). For species in which females first reproduce at one and two years, lethal control will be more efficient than reproductive control in reducing populations when the ASR is greater than about 0.56 and 0.23, respectively. For species in which females first reproduce at three years, lethal control always will be more efficient than reproductive control in reducing populations.

This paper has been peer reviewed.

Table 2. Parameter values used in Population Models 1 to 4 that result in stable annual population levels for 11 vertebrate species that are sometimes pests.

	Population Parameter Values[a]									
Species[b]	JSR	ASR	ESR	EPRA	FFR1	FFR2	FFR3	FFR4	FFR5	MCF
GFBT	0.635	0.798	0.80	0.5	0	1	1	1	1	1.25
BRAT[c]	0.670	0.773	0.80	3.0	1	1	1	1	1	1.29
WTDR	0.570	0.700	0.89	0.9	0	0.8	1	1	1	1.43
COYT	0.250	0.603	0.88	2.5	0.3	1	1	1	1	1.67
BEAV	0.500	0.669	0.85	1.8	0	0.2	0.6	1	1	1.49
CAGO	0.300	0.699	0.60	3.0	0	0.3	1	1	1	1.43
DCCO	0.353	0.771	0.50	2.0	0	0.3	1	1	1	1.30
LAGU	0.480	0.800	0.55	1.1	0	0.3	1	1	1	1.25
BHCO	0.210	0.454	0.13	20.0	1	1	1	1	1	2.20
COGR	0.400	0.562	0.50	2.4	0.8	1	1	1	1	1.78
RBQU	0.223	0.500	0.80	2.8	1	1	1	1	1	2.00

[a]Estimates for parameters derived from literature (see below), or, when not available, by applying reasonable approximations that resulted in stable population.

[b]GFBT = giant fruit bat, BRAT = black rat (Dolbeer et al. 1988); WTDR = white-tailed deer (Hayne 1984); COYT = coyote (*Canis latrans*), Bekoff 1982); BEAV = Beaver (Hill 1982); CAGO = Canada goose (Bellrose 1976); DCCO = double-crested cormorant (Bedard et al. 1995); LAGU = laughing gull (Burger 1996); BHCO = brown-headed cowbird (Lowther 1993); COGR = common grackle (Peer and Bollinger 1997); RBQU = red-billed quelea (Jones 1989).

[c]JSR and ASR are monthly rates; EPRA/4 months; females reproduce at four months.

This paper has been peer reviewed.

Table 3. Estimated relative efficiency of reproductive and lethal control based on numbers remaining after three years from an initially stable population of 1,000 individuals in which reproductive or survival rate is reduced annually by 50% (using Population Model 2 [rats] and Model 1 [all other species]).

	Number Remaining After Three Years			Relative Efficiency[a] of Lethal to Reproductive Control (RC/LC) After Three Years	
		Lethal Control (LC)			
Species	Reproductive Control (RC)	≥Age 0[b]	≥Age 1[c]	≥Age 0[b]	≥Age 1[c]
Fruit bat	731	125	191	5.8	3.8
Laughing gull	720	125	180	5.8	4.0
D.C. cormorant	673	125	183	5.4	3.7
White-tailed deer	639	125	212	5.1	3.0
Beaver	624	125	199	5.0	3.1
Canada goose	607	125	193	4.9	3.1
Coyote	486	125	264	3.9	1.8
Common grackle	460	125	349	3.7	1.7
Brown-headed cowbird	338	125	462	2.7	1.3
Red-billed quelea	368	125	421	2.9	0.7
Black rat	97[d](406)[e]	307[c]	675[d]	0.3[c]	0.6[d]

[a]Efficiency ratios presented are specific to population status after three years and will increase during additional years of treatment.

[b]Survival reduced 50% for age classes ≥0.

[c]Survival reduced 50% for age classes ≥1.

[d]Survival and reproduction of adults (≥3 months old) reduced three times/year.

[e]Survival and reproduction of adults (≥3 months old) reduced one time/year.

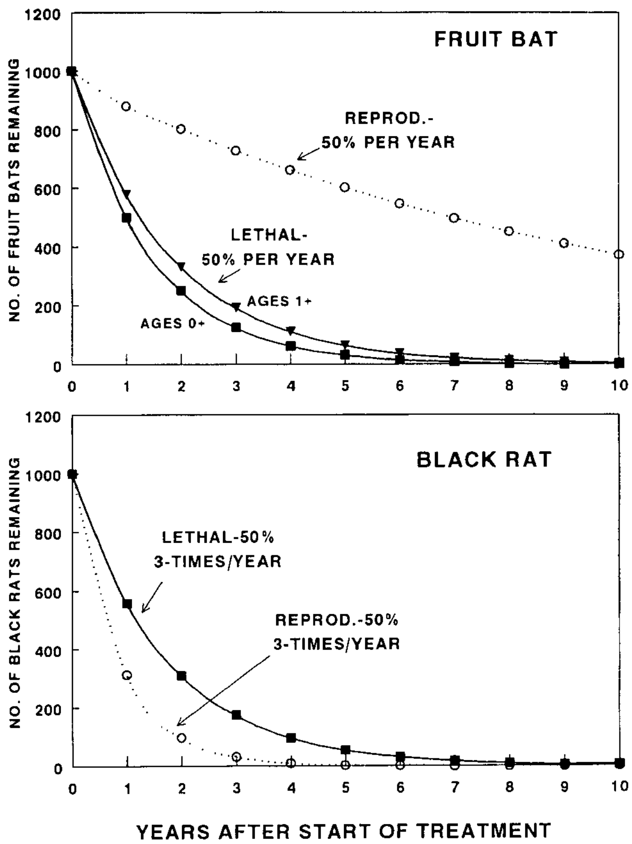


Figure 2. Relative efficiency of reproductive and lethal control (yearly 50% reduction in reproductive or survival rate from values that produce stable population) for giant fruit bats (Population Model 1) and black rats (Population Model 2).

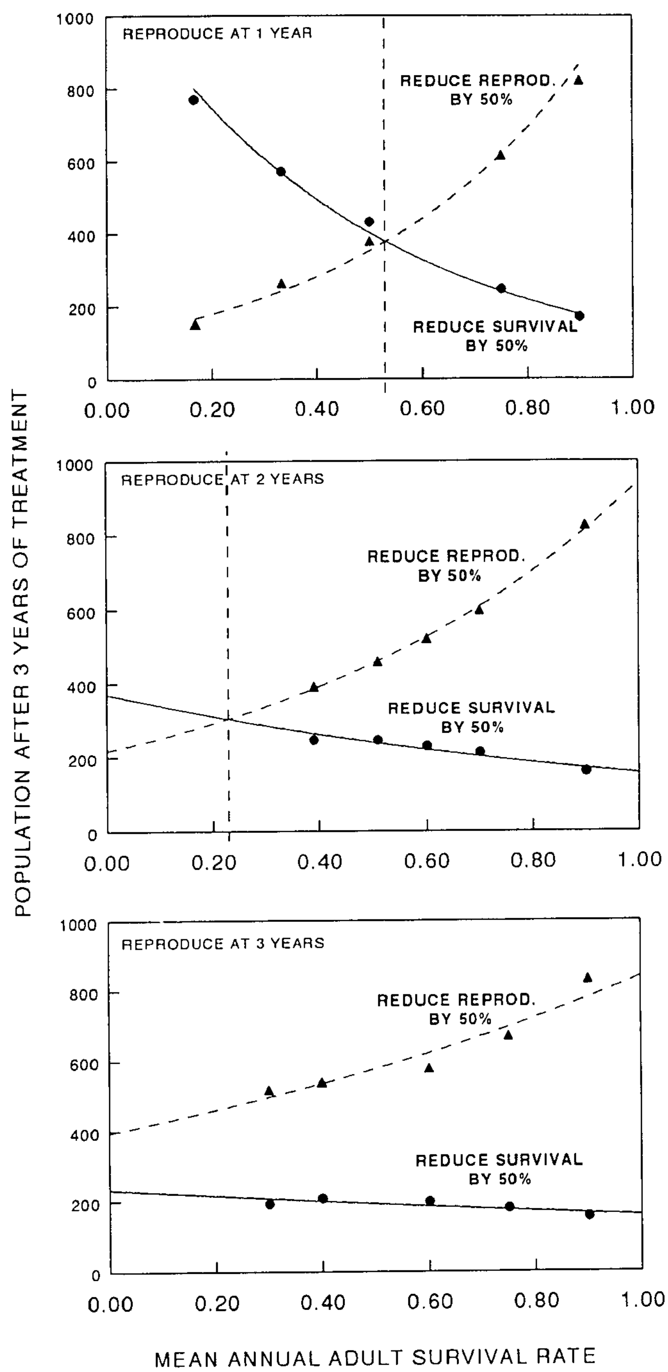


Figure 3. Relative efficiency of reproductive and lethal control (yearly 50% reduction in reproductive or survival rate from values that produce stable population) in relation to mean adult annual survival rate for hypothetical vertebrate species that first reproduce at one, two, or three years of age.

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Response of Laughing Gulls to Control (PM3)

A colony of laughing gulls on Jamaica Bay Wildlife Refuge, New York immediately adjacent to John F. Kennedy International Airport (JFKIA) increased from 15 to 7,600 nests, 1979 to 1990. During this period, there was an increase of the entire coastal New Jersey-Long Island (NJLI) population from about 31,000 nests in 1977 to 61,500 nests in 1989 to 1990 (Belant and Dolbeer 1993).

The large nesting colony next to JFKIA created a hazard for aircraft during summer because gulls frequently overflew the airport on daily foraging trips (Dolbeer et al. 1993). Because the colony was on protected National Park Service land, management options to reduce aircraft collisions with gulls (bird strikes) were limited. From 1991 to 1997, biologists shot 47,600 laughing gulls flying over the airport during May to August, reducing gull strikes by 66 to 89% (Dolbeer and Bucknall 1998).

This management action, involving the removal of a relatively large number of gulls within a major metropolitan area, received intense media and public scrutiny (USDA 1994). Therefore, it was imperative to document the impact of killing on the regional population to assure the public that responsible management actions were being implemented (Belant and Dolbeer 1993). PM3 provided an objective means of predicting the impact of this shooting program on the NJLI population and putting the level of kill into perspective with regard to the total population.

First, PM3 estimated that in addition to the 131,000 nesting birds censused in 1989 to 1990, the population contained about 60,000 non-nesting adults (≥ 1 year old, Table 4). Second, PM3 predicted a 26% decline in the NJLI nesting population from 1989 to 1995, whereas actual surveys estimated about a 33% decline. Finally, if an egg-oiling program had been conducted in which the number of nests oiled was equivalent to the number of gulls killed, PM3 predicted a decline of about 8% from 1989 to 1995. Neither the national nor northeast regional (Virginia to Maine) population of laughing gulls has declined during the years (1991 to 1997) of the shooting program, based on North American Breeding Bird Survey results, 1966 to 1996 (Burger 1996; Sauer et al. 1997).

Response of Blackbirds to Control (PM4)

From 1974 to 1992, an estimated 38.2 million blackbirds (*Icterinae*) and starlings (*Sturnus vulgaris*) were killed in the southern United States by surfactant applications to winter roosts (Dolbeer et al. 1997). These management operations had no detectable impact on subsequent nesting population levels in the northern United States (Dolbeer et al. 1997), a finding that had been predicted (U.S. Dept. Inter. 1976) based on simulations from an earlier version of PM4 (Dolbeer et al. 1976). The greatest number of birds removed during a single winter was 4.2 million common grackles in 1977. A simulation with PM4 of the annual population cycle of common grackles in the eastern United States demonstrated the minimal impact of removing 4.2 million birds during January (Figure 4).

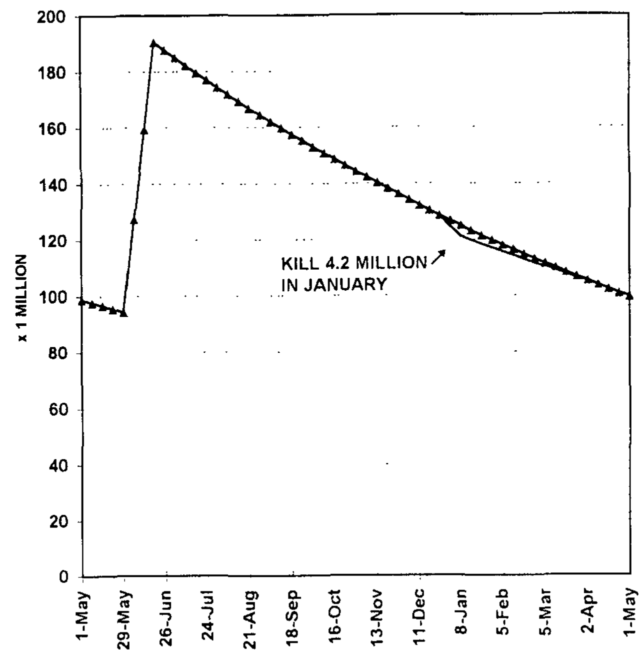

Figure 4. Simulated annual cycle of population of common grackles in eastern North America (Population Model 4) showing no control and the removal of 4.2 million birds in winter 1978 (Dolbeer et al. 1997).

DISCUSSION

Population models provide an essential framework for understanding the population dynamics of wildlife species to guide the development, evaluation and defense of management decisions. First, such models provide predictions of parameter values needed to produce a stable or changing (e.g., 10% mean annual increase) population level for a species. Second, models provide estimates of population responses to various control strategies, either hypothetically (PM1, PM2) or for actual situations (PM3, PM4). As demonstrated in this paper, these models can provide critical perspective into the impact, or lack thereof, that a given level of reproductive or lethal control has on a population in an actual or proposed management action.

Two criticisms of population modeling as a management tool are that data on parameter values often are inadequate and that models cannot account for all variables influencing populations. The author contends that these criticisms are not valid. First, there are adequate population data for many situations with species such as gulls, deer, waterfowl and blackbirds. Furthermore, for those situations or species with meager data, the author contends these criticisms provide even greater justification for modeling. Obviously, models cannot account for all variables influencing populations, and model output always should be viewed cautiously in light of the assumptions, model constraints and quality of data. However, management decisions are made whether or not models are used. Models provide an objective

Table 4. Predicted response (Population Model 3) of laughing gull population on Long Island, New York and New Jersey to killing (actual) and egg oiling (hypothetical) in relation to field-based estimates of nesting population, 1977 to 1997 (numbers x 1,000).

			Predicted Nesting and Total Population			
			After Killing[c]		After Egg Oiling[d]	
Year	Estimated Nesting Population[a]	Number of Gulls Killed[b]	Nesting	Total[e]	Nesting	Total[e]
1977	61					
1985	122					
1989	131		131	190	131	190
1990			131	190	131	190
1991		14.2	121	177	131	190
1992		11.8	113	161	131	182
1993		6.5	107	151	129	176
1994		3.7	103	147	124	174
1995	88	6.2	97	140	121	173
1996		2.0	95	137	120	170
1997		3.2	93	133	118	170

[a]Based on actual nest censuses summarized by Belant and Dolbeer (1993) and Dolbeer et al. (1998).

[b]Birds shot at John F. Kennedy International Airport (93%, Dolbeer et al. 1998) and Atlantic City International Airport (7%, J. Floyd, U.S. Dept. Agric., unpubl. data).

[c]In addition to the number of birds actually killed, it is assumed 50% of short birds resulted in nest failure.

[d]Hypothetical simulation: number of nests oiled (100% effective) equal to the number of birds killed.

[e]Total population includes nesting birds plus non-breeders (age 1 to 5) determined from age composition and estimated fraction of population breeding in each age class (Table 2).

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framework whereby assumptions and parameter estimates are explicitly stated in numerical values and mathematical relationships. Subsequent simulations produce testable hypotheses that can be challenged via experimentation. Models simply make those decisions more objective and provide professional wildlife managers and the public with an improved means of arriving at, justifying, debating and evaluating decisions (Starfield 1997).

Modeling also clearly identifies parameters for which improved data are needed for a species or situation, thereby focusing research efforts so that more reliable predictions can be made and defended. For example, data for key parameters such as the fraction of females breeding in younger age classes (e.g., age classes 2 to 3 for double-crested cormorants; Bedard et al. 1995) are often meager, making estimates of reproductive rate uncertain. Also, estimates of the total population being managed are often lacking (e.g., Torres et al. 1996), making evaluation of management impacts difficult even if good data were available on population parameters such as survival and reproductive rates. By requiring estimates for each of the population parameters, a manager quickly prioritizes critical data gaps.

Population simulations using PM1 and PM2 demonstrated that for most of the vertebrate pest species considered in this paper, lethal control will be more efficient than reproductive control in reducing population levels. This finding conflicts with the growing public desire for nonlethal methods of solving wildlife damage problems of which reproductive control is currently fashionable, at least conceptually (Kirkpatrick and Turner 1985). Professional biologists should not allow these outside pressures to cause them to stray from the fundamental principles of wildlife management, of which population dynamics is the cornerstone.

Reproductive control may have a place in wildlife management. But the author contends that efforts for reproductive control should focus on those species for which the concept is most likely to be successful, such as rodents and small birds. Furthermore, if reproductive control strategies are developed and used on long-lived species such as deer and geese, biologists need to be honest with the public about the length of time required for such strategies to reduce populations relative to lethal control.

In conclusion, as professional biologists practicing wildlife damage management, we have an obligation to be leaders in taking appropriate management actions based on the principles of wildlife science, and we betray our profession when we become followers of vacillating public opinion. We should not be afraid to recommend and implement lethal control to manage legitimate damage situations when: 1) such actions are justified based on the population status and dynamics of the species; 2) alternative control methods are impractical or less efficient; and 3) outcomes can be monitored to evaluate the impact of killing on target populations and in solving problems. Understanding the population dynamics of wildlife species is the cornerstone to successful management, and population models such as described in this paper will be essential for this task in our increasingly crowded world in the years to come.

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THE BEAVER—A SOUTHERN NATIVE RETURNING HOME

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ABSTRACT: Beaver populations, extirpated in the previous century, have returned to the South often causing severe damage to timber and other resources. Many landowners perceive trapping programs as being ineffectual, perhaps because most programs are overwhelmed with immigrant beavers. To quantify immigration patterns, from November 1984 to May 1985, resident beaver were removed from a 1,619 ha study area in west Tennessee and for the next 40 months immigrants were captured within one month of immigration. Removal patterns of the resident population (169 beavers) suggest that bounty systems may be ineffectual to protect natural resources. Immigration was low (5.5 beavers) June to September and significantly ($P \leq 0.05$) higher (46.4 beavers) October to May.

KEY WORDS: beaver, *Castor canadensis*, damage, trapping, control, immigration, bounty

Proc. 18th Vertebr. Pest Conf. (R.O. Baker & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 1998.

INTRODUCTION

It would be difficult to trace the course of American history without including the beaver (*Castor canadensis*). However, it is a story, especially a southern story, best told in three parts. Prior to European settlement, North American beaver populations are speculated as ranging between 60 to 400 million individuals (Naiman et al. 1986). Insatiable European demand for beaver pelts provided a powerful incentive for pioneer trappers. Annually, from 1620 to 1630, more than 10,000 beavers were taken from Connecticut and Massachusetts. In the decade following 1630 an estimated 800,000 were trapped from the Hudson River watershed in western New York (Naiman et al. 1986).

As eastern beaver populations declined, early 19th century expeditions were outfitted by speculators and sent westward to exploit new territories. The fur industry was so pervasive that in many areas beaver pelts as expressed by the "beaver standard" became a basic unit of exchange (Wesley 1978).

Trapping continued unabated during the 1800s and early 1900s, extirpating populations from many parts of their native range (Wesley 1978; Jenkins and Busher 1979). Beaver habitat also was lost as an expanding rural population practiced open range grazing which destroyed small trees, grasses and forbs along the watercourses (Milne and Milne 1960). And, since 1834, an estimated 195,000 to 260,000 square kilometers of wetlands have been converted primarily to farmland (Naiman et al. 1986).

Although scattered, remnant populations continued to exist over most of the beaver's southern range (Shultz 1954), beavers were virtually nonexistent in Alabama (Barkalow 1949; Moore and Martin 1949), South Carolina (Penny 1949), Virginia and West Virginia (Swank 1949), Tennessee (Shultz 1954), and Mississippi (Cook 1965) by the late 1800s. The first part of the story was made complete as several human generations lived out their lives on the southern landscape, laboring under the supposition that the bottomland systems were—and for all they knew—always had been, complete without the beaver.

ACT TWO OF THE BEAVER'S STORY

Restocking programs were initiated in many states by the mid 1900s (Saylor 1946; Shultz 1954; Cook 1965; Beshears 1967; Wigley 1986). Decreased trapping pressure along with an increasingly urban society enabled rapid expansion of native and reintroduced beaver. The South's innumerable streams provided superb travel lanes to an expanding beaver population and it would have been an ecological mystery if the beaver had not eventually reoccupied its old haunts. Inadvertently, like a welcoming party thrown for the wrong person, much had been done to prepare for its return.

During the beaver's absence, tremendous hardwood forests developed along many southern watercourses. These forests had remained unmolested, except by axe and chainsaw—shovel and dozer—prior to living memory. Roadways and railways crossed the bottomlands atop earthen dikes, allowing rivers to squeeze through under the bridges. Channelized streams were lined with soil depositions along both banks, except where the tributaries entered. To the beaver these were ready-made dams with holes that could be plugged. Many farmlands that were habitually too wet had been abandoned to grow up in thick stands of willow and birch saplings. These lands provided excellent food sources for the beaver.

By the mid-1970s, on many watersheds within the region, beavers were perceived as an "exotic" nuisance species whose dam-building and girdling activities heavily damaged forests. Bullock and Arner (1985) estimated that the beaver-induced loss to Mississippi's economy from 1975 to 1985 approached $2.4 billion. Miller (1986) concluded that "the beaver is the vertebrate animal causing the most damage to Southern forests at the present time."

Wigley (1986) surveyed 3,369 rural, noncorporate landowners owning more than 2 ha of land in Arkansas to estimate the impact of beaver populations in that state. Responses from 1,716 individuals holding 312,006 ha, or 2.3% of the land base, indicated that beaver activity had negatively impacted 342,105 ha statewide. Some form of beaver damage was reported by 32% of all respondents with 50% describing damage as substantial or severe.

About a quarter of all landowners reporting damage stated a willingness to pay for beaver removal. Although trapping could be demonstrated as the primary force in reducing populations prior to the 1800s, trapping was largely perceived as ineffectual by many respondents.

Part two of the beaver's story was complete. The southern native had returned home in force and it was necessary for land managers to learn about this "new" threat to the resources under their care.

BEAVER BIOLOGY

A beaver colony is the basic unit defining populations on the landscape. A typical colony consists of five to eight beavers with two adults (parents), the kits of the current year, and yearlings from the previous year (Busher et al. 1983), occupying a pond or stretch of stream, utilizing a common food supply and maintaining a common dam or dams (Bradt 1938).

Beavers are generally monogamous (Kleiman 1977; Svendsen 1989). Pair bonds can be formed throughout the year, but most commonly in late summer and fall (Svendsen 1989). The breeding season generally occurs from January to March in colder climates (Svendson 1980), but may occur in December or January in the South (Hill 1982). Gestation is approximately 100 days (Bergerud and Miller 1977). Kits weigh approximately 0.5 kg and average 38 cm long including a 9 cm tail. Litter size ranges from 1 to 9, averaging 3.7 (Svendsen 1980). First parturition normally occurs at age three, but can occur as early as age two depending on habitat or social structure of the colony.

Beavers could not persist over a large part of their native range without adequate supplies of woody vegetation to support them during fall and winter months. Over time, a colony's foraging activities will decrease the amount of woody vegetation around their impoundment. Beavers can react to a reduction in forage by moving to another colony site (Svendsen 1989) or by adding to pre-existing dams and backing water closer to new food supplies. Beavers are capable of building large dams. One dam in Montana was 650 m long, another in New Hampshire 1,213 m long (Rue 1969), and one in Wyoming was 5.4 feet high (Rue 1969).

Four types of beaver movements have been listed (Bergerud and Miller 1977): 1) movement of an entire colony; 2) wandering of yearlings; 3) dispersal of two-year-olds away from the natal territory; and 4) movement of adults who have lost a mate. Young beaver generally disperse from the natal colony during the season of their second birthday, coinciding with parturition of the adult female (Bradt 1947; Townsend 1953; Beer 1955; Libby 1957; Brooks et al. 1980). Although there seems to be an inherent tendency to leave, there is also indirect evidence that two-year-olds are driven from the colony by dominant adults (Hodgson and Larson 1973).

A number of beaver control methods have been examined over the years, including poisons (Hill 1976), chemosterilants (Arner 1964; Hill et al. 1977), surgical sterilization (Brooks et al. 1980) and introduction of alligators (*Alligator mississippiensis*) (Hill 1976). All of these are incomplete, impracticable or are contrary to public acceptance.

Trapping, the method by which beaver populations were once extirpated, remains as the best means available to produce measurable success. Yet, as was demonstrated by Wigley's (1986) survey, many landowners have no faith in trapping.

OBJECTIVES

The objectives of the Ames study were to: 1) record removal rates of a resident beaver population subjected to an intense trapping regime; 2) determine if immigrant beavers attempted to re-colonize the trapped-out area; and 3) quantify immigration patterns in a reasonable manner.

STUDY AREA AND METHODS

This study was conducted largely on the Ames Plantation, a 7,500 ha landholding administered cooperatively by the Hobart Ames Foundation and the University of Tennessee Agricultural Experiment Station (Houston et al. 1995). Ames Plantation is in the upper headwater basin of the North Fork of the Wolf River, located in the Mississippi Embayment section of the Gulf Coastal Plain physiographic province, 80 km east of Memphis, Tennessee, and 80 km southwest of Jackson, Tennessee.

A 1,619-hectare study area was defined in the floodplain of the North Fork Wolf River beginning at the downstream departure of the river from Ames Plantation property and continuing upstream approximately 12.8 kilometers until the river became intermittent. There were numerous small tributaries along this length. At the lowermost point of the study area the North Fork Wolf River averaged 0.5 to 1.0 m deep and 5 to 7 m wide.

Beginning in November 1984 and continuing through May 1985, intensive trapping removed all beavers from the 22 active colonies in the study area. Individual locations were considered trapped-out if beaver activity (e.g., dam repair, tracks, cuttings) was not observed during repeated visits (spanning several days) to the site (Peterson and Payne 1986). No attempt was made during this period to distinguish initial populations from immigrants.

From June 1, 1985 through September 30, 1988, all colony sites remained under surveillance and beaver attempting to recolonize were removed within one month of immigration to the site. During this time all captures were considered to be immigrants.

Trapping was accomplished primarily with the Conibear 330 (about 90%) and limited use of the wire snare (Hill 1976 and 1982; Weaver et al. 1985). The most productive technique was to create a small break or series of breaks with hand tools in the major dam and place one or several Conibears in or near the breach. Escaping water stimulated colony members to attempt repair. Other common sets included those on runways across the top of dams or sets in association with well worn feeding runs.

If scavaging did not prevent acquisition, the lower mandible of each specimen was extracted for age determinations (van Nostrand and Stephenson 1964; Larson and van Nostrand 1968).

It was assumed that the study site was readily available to immigrants. Based on aerial surveillance during the course of the study by Tennessee Division of Forestry personnel, beaver populations remained consistently high on downstream portions of the river (Charles Riddell, pers. comm. 1987). The number of beavers caught from June 1985 through September 1988 was summed by four-month periods. February through May was viewed as the time when two-year-olds dispersed from natal colonies, representing a high probability period for immigration. The other two periods (October to January and June to September) were fixed by choosing this period.

To maintain the assumptions necessary for analysis of variance, the total number caught by individual four-month periods were transformed to log (sum + 1) and trapability was assumed equal for each time period. Analysis of variance was conducted on transformed data to determine if immigration was significantly different among four-month time periods.

RESULTS AND DISCUSSION

During the first seven months of the study, 169 beavers were captured; however, monthly capture totals were not uniform. Generally, fewer beavers were captured each month and, by the end of the seven-month period, pre-study resident populations were judged to have been removed (Figure 1).

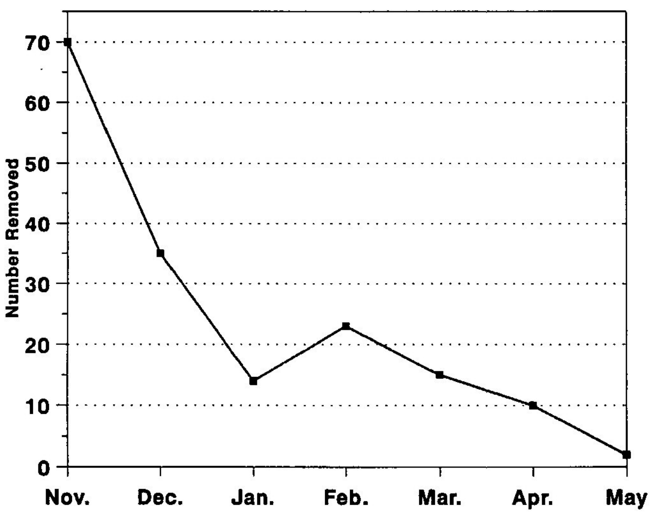

Figure 1. Removal of initial beaver populations from the Ames Plantation Study Area, Fayette County, West Tennessee, November 1984 through May 1985.

From June 1985 through September 1988, 162 beavers attempting to recolonize original or new sites were removed. Recolonization attempts were relatively low during the period June to September averaging 5.5 immigrants, significantly less than the periods October to January (22.7 immigrants) and February to May (23.7 immigrants), which did not differ significantly (Figure 2). The interval from the first of October through the end of May accounted for 89.6% of all average yearly immigration.

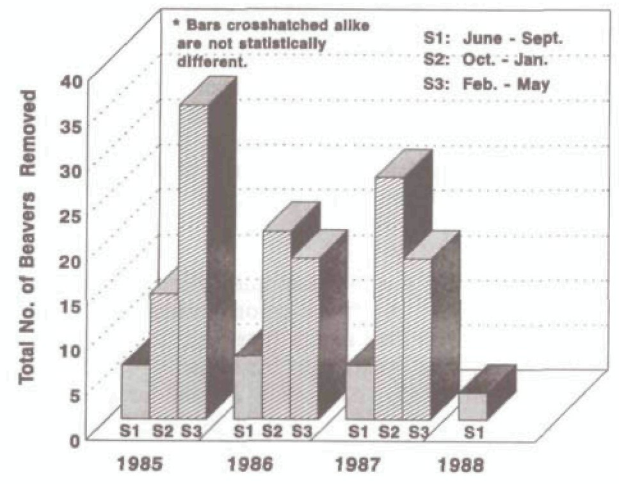

Figure 2. Total number of immigrating beavers removed from Ames Plantation Study Area, Fayette County, West Tennessee, June 1, 1985 through September 30, 1988, by four-month trapping period.

In this study 89.4% of all beaver on which age could be determined were four years old or less (Table 1). Immigrants in the one to two year age class were prominent throughout the year. This age class made up 46.3% of all immigrants during the February to May period. Beaver in the zero to one age class made up 22.5% of all captures, being especially prevalent October to January (34.8%). Only three individuals were estimated older than eight years of age, with the oldest a 34.2 kg, 12-year-old female that was carrying four near term fetuses.

THE QUESTION OF BOUNTY SYSTEMS

These results suggest that the use of "bounty systems" to control beavers on a small watershed may be ineffectual. During the first month of the study 70 beavers were caught. Under a bounty system, this might represent adequate economic reward to a trapper. However, catch totals were halved during the following month and halved again the next. Quickly diminishing returns likely would force abandonment of control efforts.

Also, the authors noticed that the older beavers at each colony site tended to be caught first (Houston et al. 1995). The removal of either or both adults has been suggested to stimulate sexual activity in remaining yearlings (Brooks et al. 1980). Potentially increased recruitment within the residual population, along with immigration, could replenish beaver populations quickly.

Generally, the control "domain," an ownership, watershed or county, will be surrounded by high beaver populations. As catch rates and monetary returns diminish within this domain, the bounty trapper is forced to: 1) quit; 2) move to more productive trapping sites within the domain; or 3) move to more productive trapping areas outside the control domain. Although bounties may cause impressive numbers of beavers to be

Table 1. Total number of beavers immigrating into the Ames Plantation study area, Fayette County, West Tennessee, June 1, 1985 through September 30, 1988, by month and age class.

	Age Class (years)								
Month	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8+
January	3	2	-	3	-	-	-	-	-
February	4	3	2	3	-	-	-	-	1
March	2	13	4	-	-	-	-	-	1
April	2	13	4	3	-	-	-	2	-
May	2	2	3	2	1	-	-	-	-
June	1	3	3	-	1	-	-	-	-
July	-	3	1	2	-	-	-	-	-
August	1	1	1	-	-	-	-	-	-
September	1	-	2	1	-	-	-	-	1
October	7	2	2	2	-	-	-	-	-
November	10	3	8	-	-	1	1	-	-
December	3	4	4	8	1	-	-	-	-
Totals	36	49	34	24	3	1	1	2	3

caught quickly, little would be accomplished to protect a specific resource at a specific site. A remnant population probably would remain to continue the threat.

However, this study also suggests that persistent trapping can extirpate beaver populations. In the face of sustained and sufficient economic pressures applied over large regions (e.g., greatly inflated pelt prices) beaver populations will require careful management to prevent over exploitation.

IMMIGRATION

Beaver immigration into the 1,619 ha study area began quickly and persisted throughout the duration of the study. Beavers repeatedly recolonized idle colony sites, likely because these sites possessed favored habitat features (Houston et al. 1995). The preponderance of immigration was expected to occur February through May, when young adult beaver disperse from natal territories in search of mates and suitable habitat. Unexpectedly, immigration totals from October through January were equally high and not statistically different from February through May.

Working in Montana, Townsend (1953) noted that September was the month of greatest dam building and was the time when two-year-olds "settled down" into their new home. Svendsen (1989), determined that pair bonds in an Ohio study were formed predominately in the late summer and early fall. In west Tennessee the period of greatest dam building and "settling in" may occur later in the year, perhaps October to December. First frost usually occurs during late October at Ames Plantation as opposed to a normally earlier onset of harsh weather in Montana and Ohio. Needing a dependable, woody food source, young adult beaver apparently attempt to "settle down" as the weather grows colder and herbaceous food supplies dwindle. Also, in Tennessee, October through November represents a time when deciduous leaves are in their greatest abundance in streams, representing an excellent source of dam building materials.

Summer immigration (June to September) was significantly lower than the remaining two periods. Where beaver populations are high, and colony sites difficult to locate, the beaver's ability to subsist on relatively abundant herbaceous food supplies may delay the urgency of finding a suitable permanent home. After dispersal from natal sites, a proportion of young beavers may remain "at large," representing a surplus population available to fill suitable habitat or replace lost mates in the fall (Beer 1955; Peterson and Payne 1986; Svendson 1989). In the authors' study, June through September encompassed the majority of the growing season; and timber innundated for any significant duration during this timeframe likely would die. Therefore, while immigration may be relatively low, any dam repair by immigrants during this period would represent significant peril to growing stock.

More than 89% of all immigrants into the control domain were four years old or younger. This was expected because most wildlife populations are heavily skewed toward younger classes and young adult beaver are more likely to move (Beer 1995; Leege 1968). It was unexpected that 22.5% of all immigrants would be less than one year old, an age class presumed to remain near familiar natal surroundings.

In this study kits often were removed from colony sites where adult immigrants, presumably the parents, also were present. Likely, pregnant females gave birth onsite or arrived with kits in tow (Bergerud and Miller 1977). Kits caught from July to December frequently were unaccompanied by adults and sometimes attempted to repair the dams in rudimentary fashion. The erratic fashion of these episodes, with regular abandonment of the site, left the impression that these young beaver came from outside the study area and were caught while simply "exploring" (Bergerud and Miller 1977).

SUMMARY

A survey of landowner attitudes toward beaver damage and control in Arkansas reported that respondents often perceived control measures such as trapping to be largely ineffective (Wigley 1986), despite having been demonstrated successfully elsewhere (Hill 1976). Such responses probably represent unfamiliarity with successful trapping techniques and that the average landowner likely cannot differentiate between initial populations and immigrants. The Ames study suggests that effective beaver control will seldom be a "one shot deal." By removing a colony from a specific site, beaver habitat is made available. It is likely that immigrants will discover the available habitat and attempt recolonization.

Yet, unfocused control programs that are "aimed at all beaver" and lack the sustained economic incentive to greatly reduce populations over large regions, is only a partial solution and will generally fail to protect specific resources. Furthermore, extirpation of any species from major portions of its range is socially unacceptable.

A successful control program must first define the resource that it is designed to protect (Houston et al. 1992). This establishes a domain that focuses control efforts. There must be a determination of the specific beaver activity that places the resource at risk. This, along with an understanding of beaver biology, can lead to the development of a successful control strategy.

For example, a landowner may have no desire to remove a beaver colony from a farm pond, but cannot tolerate girdling of the surrounding ornamental trees. If the ornamental trees are not damaged, then control can be judged successful. Barriers around individual trees may provide sufficient protection and the control program would be a success.

However, if beaver-caused inundation poses a threat to a large timber tract, then a control program should not be judged by the number of beaver removed, but by the absence of water and survival of the timber. The water can be removed by breaching the dams. To maintain the breaches, a trapping program would be required to catch resident beaver and subsequent immigrants. However, this would not require removal of beaver outside the control domain.

Perhaps, in this case, resident beaver populations could be removed by the first of the growing season. If summer trapping is legal, removal of immigrants would require relatively little effort during the growing season when immigration rates are expected to be lower. In the fall, when the timber becomes dormant, inundation might pose little threat and recolonization could be allowed. Beavers are territorial (Bergerud and Miller 1977) and immigrants might effectively obstruct further immigration per site, lowering the effort needed to remove populations prior to the onset of the next growing season (Houston et al. 1995). However, trapping during the growing season is a physically demanding endeavor, and within the geographical range of the cottonmouth moccasin (*Agkistrodon pisivorous*) requires extreme wariness on the part of workers.

PART THREE—AN ONGOING STORY

The third part of the beaver's story is a work in progress and involves the ongoing drama of a native whose return home has been met with concern by those whose land the beaver shares. And, because much has changed while the beaver was in exile, it will be a story of learning to control the beaver's genuinely negative impacts while recognizing and capitalizing on the equally genuine positive factors. Likely, the beaver is home to stay. As such, control programs will be executed within relatively small domains surrounded by beaver populations. Potential immigration into these domains makes it probable that control programs, or at least vigilance and a preparedness to begin control measures, will be as perpetual as the resource they are designed to protect.

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THE POTENTIAL FOR MANAGING URBAN CANADA GEESE BY MODIFYING HABITAT

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ABSTRACT: Urban Canada goose (*Branta canadensis*) populations have grown rapidly during the past three decades. This paper reviews short-term and long-term urban goose management techniques, and using data for the Twin Cities of Minnesota, assesses the potential utility of habitat modification. Ninety-four percent of Twin Cities damage complaints occurred during the brood-rearing period, 5% in fall, and >1% in spring and winter. The potential for reducing goose damage by altering nest habitat is insignificant, brood-rearing habitat high but expensive, and fall and winter habitat low and also costly. Fences effectively thwart flightless geese but can entrap birds leading to starvation. Cost projections for programs limiting the Twin Cities summer population at 25,000 were $125,000/year for relocation, $325,000/year for processing for human consumption, $12.3 million/25 years for wire fences, $33.9 million for tall grass prairie, and $1.8 billion for ground juniper (*Juniperus* spp.). Human preference for savanna and the fear of urban crime associated with dense vegetation may hamper implementation of goose habitat modification.

KEYWORDS: Canada goose, *Branta canadensis*, damage, urban management, habitat modification potential, effectiveness, cost estimates, crime

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INTRODUCTION

Many urban Canada goose populations have grown exponentially during the past three decades (Ankney 1996; Rusch et al. 1996; Zenner 1996; Cooper and Keefe 1997). Complaints of goose damage have been reported for Anchorage, Vancouver BC, Seattle, Denver, Kansas City, Chicago, Milwaukee, Winnipeg, Toronto, Boston, Washington DC, and other urban centers (Conover and Chasko 1985; Ankney 1996; Cooper and Keefe 1997). Damage complaints include: droppings on golf courses, docks and swimming beaches, playgrounds, athletic fields, park shorelines, residential yards, and commercial grounds (Conover and Chasko 1985; Cooper 1987; Cooper and Keefe 1997), water quality reduction (Manny et al. 1994), and highway (Cooper and Keefe 1997) and aircraft hazards (Cooper 1991; Dolbeer 1996).

Cooper and Keefe (1997) divided urban goose management approaches into short-term redistribution techniques and long-term population management procedures. Short-term methods prevent or reduce goose use of a specific site for a period of days to several weeks, forcing the birds to use alternative sites. Long-term approaches reduce the population by decreasing reproduction or survival, or by removal of the geese. Short-term, redistribution procedures include prohibition of artificial feeding, hazing using humans (Aguilera 1989), vehicles, dogs, swans, swan or dead goose decoys, and sounds (Mott and Timbrook 1988), erecting access barriers such as wire, rope, or bird-scare tape fences, and taste aversive chemicals (Conover 1985; Cummings et al. 1991; Belant et al. 1996; Gosser et al. 1997). Reproduction has been inhibited by embryocides (Baker et al. 1993; Christens et al. 1995), egg removal (Wright and Phillips 1991; Cooper and Keefe 1997), and vacsectomization (Converse 1985). Populations have been reduced by sport hunting, shooting (Cooper 1991; Cooper and Keefe 1997), capture and relocation of goslings and/or adults (Blandin and Heusmann 1974; Martz et al. 1983; Cooper 1987; Cooper and Keefe 1997), and capture and processing for human consumption (Cooper and Keefe 1997).

Habitat modification techniques can have both short- and long-term effects. For example, the replanting of upland grass with dense shrubs may eliminate goose use at a specific site. But, if the geese find adequate forage elsewhere, the effect would be short-term, whereas extensive turf conversion leading to insufficient forage and higher mortality, would have a long-term impact. While frequently mentioned as a potentially effective and environmentally sound approach (Gosser et al. 1997; Grandy and Hadidian 1997; Garner Lee Limited 1997), a comprehensive evaluation of the utility of habitat modification is lacking. Utilizing Twin Cities of Minnesota goose population, goose damage site, wetlands data (Cooper and Sayler 1974; Sayler 1978; Cooper 1987, 1991; and Cooper and Keefe 1997; Minnesota Department of Natural Resources unpubl.) and existing literature, this paper uses a "what if" approach to assess the potential biologic and economic efficacy, social acceptability, and application of landscape alterations as urban goose management tools.

TWIN CITIES GEESE AND GOOSE HABITAT

The Twin Cities Metropolitan Area (Metro), latitude 45° longitude 93°, is a 6,076 km^2 midwestern urban complex with 193 municipalities and 2.5 million human residents. Pleistocene glaciation left the area with a flat but diverse landscape of lakes, kettle ponds, wetlands, and small streams separated by low moraines and outwash plains. In spite of wetland drainage for development, the Metro presently contains 303 lakes and 2,800 type 3, 4, or 5 palustrine wetlands (Minnesota Department of Natural Resources unpubl.; Cowardin et al. 1979) larger than 1.1 ha. Wetlands cover 37% of the Twin Cities, three major rivers—the Mississippi, Minnesota, and St. Croix, and numerous small meandering streams flow through the Metro area, providing additional goose habitat.

There are no historical records, but based on the eight Metro area "Goose Lake" place names, breeding Canada geese were likely present prior to 18th century European settlement. No breeding wild geese were reported in the Twin Cities until the species was re-introduced in 1955 (Hawkins 1968). Once established, the goose population grew exponentially until population management was implemented in 1982 (Cooper and Keefe 1997). Ankney (1996) reported similar growth of re-introduced Canada geese in Ontario, and Zenner's (1996) data for the Mississippi Flyway giant Canada geese are indicative of similar expansions in other midwestern re-introduced populations. Using breeding habitat as the limiting factor and conservative productivity indices, Cooper and Keefe (1997) estimated the summer Twin Cities goose carrying capacity at 1 million birds, 40 times that of the current population of 25,000.

GOOSE DAMAGE COMPLAINTS

Goose complaint site data have been recorded from 1982 to 1997. Wetlands where citizens have complained about goose damage have expanded from a total of one in 1982 to 451 in 1997. Sites were classified by season when the problem occurred (spring-breeding, summer-brood-rearing, summer and fall-flying, and winter) and predominate human use (park shorelines, swimming beach, residential, commercial, golf, airport, etc.). Summer brood-rearing period complaints are most common (94%), followed by fall (5%), spring (<1%), and winter (<1%). The two spring complaints were from golf courses. Summer complaints came from residential sites (52%), park shorelines (17%), golf courses (16%), swimming beaches (10%), and commercial grounds (6%). The 24 fall complaints came from golf courses (46%), residential (25%), athletic fields (12%), airports (12%), and commercial sites (5%). The three winter damage reports were from an airport and two golf courses.

MANAGING THE GOOSE POPULATIONS BY HABITAT MODIFICATION

Canada goose habitat use differs during breeding, brood-rearing, late summer and fall staging, and over-wintering (Owen 1980); consequently, the potential for moderating or eliminating goose damage by changing the habitat differs by season.

Nest Habitat

Canada geese nest in a wide variety of situations. The most common sites are islands, muskrat or beaver lodges, and peninsulas (Hanson 1965; Williams 1967; Sherwood 1968; Hanson and Eberhardt 1971; Cooper 1978; Ogilvie 1978; Owen 1980; and others). Where preferred sites are limited or absent, birds utilize cliffs (Kondla 1973), abandoned eagle and heron nests (Craighead and Craighead 1949), and the flat roofs of buildings (Cooper unpubl.). When alternatives sites are lacking, Canada geese nest in colonies on islands (Klopman 1958; Ewaschuk and Boag 1972). Canada geese also readily nest in man-made structures when provided (Dill and Lee 1970; Cooper 1978).

Potential alterations of Twin Cities nest habitat for either short-term or long-term goose management are extremely limited. Drainage or filling of urban lakes and wetlands would control the geese, but would be costly, and have unacceptable impacts on other wetland wildlife species and diminish the landscape quality for humans (Ulrich 1983). Currently, all of Metro wetlands used by nesting geese are protected by Minnesota law. Nine percent of the Twin Cities 3,103 lakes and wetlands contain an average of two earthen islands. Because islands are favored by nesting geese and nest success is high on islands (Sherwood 1968; Ewaschuk and Boag 1972), removal of these sites would reduce local goose populations (e.g., at Lake of the Isles in Minneapolis where up to 60 pairs have nested). But islands are preferred breeding sites by other wildlife species, particularly ducks, herons, and egrets, thus island removal for goose management would significantly impact other species. The removal of man-made structures should be done at complaint sites; however, this would have minuscule effect on the Metro population. In the early 1970s, man-made sites were commonly provided at goose flock establishment locations; Sayler (1977) found 100 nests (30% of the total) in structures in 1973 to 1975, whereas presently, no structures currently exist at the 10 sites studied in the 1973 to 1975 period, and no structures were found at the 254 randomly surveyed wetlands in 1994 (see Cooper and Keefe 1997).

Brood-rearing Habitat

Because 94% of the Twin Cities goose damage complaints occurred during the brood-rearing period extending from mid-May to Mid-August, modifications during this interval would appear to have great promise. The high level on human/goose conflicts during brood-rearing is undoubtedly related to the restricted range (the adults are flightless for five weeks and the goslings for ten weeks), the bird's high forage demand, and the significantly higher human use of the landscape in summer, particularly shorelines for hiking, fishing, swimming, picnicing, etc.

Metro Canada goose broods hatch from April 30 to June 15 with a peak in mid-May (Sayler 1977). Pairs typically move their young to suitable nearby shoreline free of obstructing vegetation where they graze on forbs and grasses, particularly bluegrass (*Poa* spp.). If suitable shoreline is unavailable near the nest—in many cases even when it is—the goose families move to traditional brood-rearing sites within a week or two (Schultz et al. 1988). While most movements are less than 1 to 2 km and often along water courses and other greenway corridors, neckbanded Twin City pairs have traveled from 6 to 15 km from nest to brood-rearing site through city streets; in seven cases over fenced or sound-barriered, interstate highways where only arterial overpasses permitted passage.

Because the geese are traditional in their use of brood-rearing sites (Zicus 1981; Schultz et al. 1988), the wetlands used during this period are predictable, and likewise, so are the goose damage complaint locations. While many (62%) of the brood-rearing areas are along the shores of the large lakes, where parks, beaches, and suburban residential homes are concentrated, birds are also found on relatively small (<0.5 ha) golf course, apartment, townhouse, and residential ponds.

Alternatives to Managing Existing Turf

The apparent short-term solution in these cases is to discourage the geese by reducing the forage quality or availability, or by modifying the shoreline so that geese cannot move from the escape cover to the upland grazing area. Gosser et al. (1997) suggested that reduced lawn mowing or fertilization will discourage the geese. The recommendation appears sound, when present Metro geese concentrate on newly-laid, fertilized sod and consistently frequent lush mowed sections of wetland shoreline for grazing. However, there are cases of Metro geese rearing their young on unmowed, cool-season and tall prairie grasses when confined by fences. Until controlled by removal (Cooper 1991), Wood Lake Nature Center fledged 60 to 120 goslings on an area containing 11 ha of unmowed and unfertilized tall grass prairie. Similarly, the fenced 85 ha Mother Lake near the International Airport produced from 25 to 75 goslings without any management of the grass. Thus, the response to either not fertilizing or mowing is dependent upon the availability of an alternative site with suitable grass. In short, the birds will go elsewhere if an alternative is available, but will continue to use unfertilized and unmown grass if there is no other option.

Turf Replacement

Removing and replanting the upland grass with rough grasses (tall grass prairie, tall fescue, etc.), ivy, shrubs, or trees should force the birds to use alternative turf areas. However, there is a paucity of research in this area, and as the Wood Lake example illustrates, the degree to which rough grasses discourage geese is problematic if alternatives are absent. Alternative plant cover selection constraints include climatic suitability, tolerance to flooding (Metro wetland water levels vary as much as 3 m), palatability to geese, life form (i.e., dense enough to preclude goose movement to abutting grazing areas), and effect on the landscape quality to humans.

From a long-term management prespective, if sufficient shoreline was converted from grass to vegetation not used by geese, the population would become limited by available brood-rearing habitat. To assess the magnitude of habitat conversion necessary to limit the Twin Cities goose population at its present level (25,000 birds in summer), the amount of Metro shoreline in mowed grass (see Cooper and Keefe 1997), and the goose carrying capacity of a hectare of grass were estimated. Using areas of the 3,103 Metro wetlands and a shoreline development value of 1.5, Twin Cities has a minimum of 5,325 km of shoreline. Based on estimates of grass shoreline made at 227 wetlands in 1994, Cooper and Keefe (1997) found that one quarter (25.1%) of the Metro shoreline was in mowed grass or pasture. Thus 1,331 km of shoreline is currently in mowed grass or pasture. Because Metro geese have been observed leading broods through 70 m of dense cattail and woods and more than 200 m of grass to graze, it was assumed that broods would utilize at least a 100 m grass strip along the shoreline for grazing, thus the Metro contains 13,310 ha of preferred brood-rearing habitat. The literature lacks Canada goose brood carrying capacity data, consequently carrying capacity was estimated from the goose pasturing done in 1996 as part of a Metro food-shelf program (Keefe 1996). Six hundred and fifty birds (500 Adult geese and 150 immatures) maintained normal weight growth on a 23 ha bluegrass pasture from August 1 to November 15, 1995. Thus, a hectare of unmanicured pasture grass may support a minimum of 28 geese. If this is representative of the capacity of fertilized and mowed urban lawns to support geese, then Twin Cities brood carrying capacity is 373,000 birds, and 93% of the existing lawns and pastures would have to be converted to limit the population to 25,000 geese.

Vegetative Barriers

Gosser et al. (1997) and Garner Lee Limited (1997) report that vegetative barriers such as trees and shrubs discourage goose transit. Grandy and Hadidian (1997) state that by "allowing grass and shrubs to grow as little as 18 inches high in a 10 foot band around a pond can act as a deterrent to geese as it will impede their access to grazing and block their view of predators." The author's observations of goose behavior in the Metro area over the past 20 years suggest that, while locations with good visibility (see Buchsbaum and Valiela 1987; Conover and Kania 1991) are selected for grazing, the species is capable of adapting to situations where dense shoreline vegetation exists and use it as escape cover. For example, Metro geese using corporate grounds with three wooded- and two mowed-grass-shoreline wetlands separated by up to 300 m by woodlands with dense shrub understories. These birds have consistently been found on all of the wetlands during brood-rearing and observed to travel through the woods to access them. In another case, geese using a 1 ha pond surrounded by robust tall grass prairie >1 m in height, moved 120 m to graze on a 20 m bluegrass strip surrounding a commercial building. This behavior has been observed for other Canada geese. Lebeda and Ratti (1983) working with Vancouver Canada geese (*B. c. fulva*) and Byrd and Woolington (1983) studying Aleutian Canada geese (*B. c. leucoparia*) reported extensive use of density vegetation for nesting, foraging, and escape cover during brood-rearing. In fact, Lebeda and Ratti (1983) report that dense forest was preferred to water as escape cover. Both studies were of island populations with either no (Byrd and Woolington 1983) or low densities (Lebeda and Ratti 1983) of mammalian goose predators typical of non-urban midwestern habitats, i.e., red fox (*Vulpes fulva*) and coyote (*Canis latrans*). Twin Cities urban goose habitat, particularly the highly developed zones containing most of the goose damage sites, support low densities of mammalian goose predators, and thus may present an ecological setting similar to that of islands. Thus, goose brood-rearing behavior appears adaptive and dense vegetation, when predators are uncommon or absent, may be used. This hypothesis would explain the author's observations that geese during the brood-rearing period readily move through dense vegetation when visually open pathways are unavailable. More research is needed on the goose barrier attributes of vegetation prior to investing in expensive (see below) changes.

Man-made Barriers

Man-made barriers blocking passage from wetlands to upland grazing locations, particular during the flightless brood-rearing period in June and July, appear to be one of the most effective methods of limiting goose damage at specific locations. Barriers include electrified and non-electrified temporary (rope, wire, or bird-scare tape) and permanent wire or wooden fences, boulders, wooden boardwalks, construction vertical banks, and floating "bird" balls (Cooper and Keefe 1997; Garner Lee Limited 1997; Gosser et al. 1997; Smith and Craven, in press). Drawbacks to the enclosure approach included entrapment of goslings, potential impacts on other wildlife, interference with human activities, and landscape quality.

Cooper and Keefe (1997) found permanent and temporary fences to be an effective short-term technique. Because of the poor visual aesthetics of fences, Gosser et al. (1997) recommended, presumably to lessen the visual impact, that fences be placed in the water and screened with emergent vegetation; they also stated the "pond edges should be completely fenced." If the wetland contains breeding habitat and is surrounded by a permanent fence placed in this manner, available forage may be insufficient for goslings hatched within the enclosure, and they may starve. Two cases of entrapment were recorded in the Twin Cities in 1997. In one case, seven pairs of geese with 25 goslings were entrapped by homeowner-constructed fences. After 10 of the six-week old young were reported dead by a resident, the emaciated survivors were trapped and removed. In another case, 38 geese were entrapped in a newly constructed fountain basin with fences and vertical banks >1 m. When discovered, 3 of the 38, four-week old goslings were dead and the remainder emaciated. In order to assure humane use of barriers, sufficient grazing must be provided within the enclosure to accommodate the expected hatch.

Piling-supported or floating boardwalks are used at 17 Metro goose complaint sites. These structures appear to restrict goose brood travel during the first five weeks of brood-rearing when the goslings are too small to surmount them. But, based on the complaints received, once the broods can access them, boardwalks become preferred loafing sites and residents spend considerable time washing goose manure from the walks.

Like fences, abrupt shorelines (>0.5 m with $>60°$ slope) thwart goose movement. Because of the flat Twin Cities topography, they are uncommon in the Twin Cities except on the east and southeast shorelines of the larger lakes where wind-driven waves cause flooding and erosion. Here wood, concrete, or rock rip rap is used to secure the soil. Because of the construction expense, the author suspects that these structures will not be used specifically as a goose deterrent. In addition, abrupt shorelines constitute a serious human drowning risk, particular to small children (U.S. Army Corps 1991).

FALL AND WINTER

Once flying in late summer, the geese cease using many of the small wetlands and concentrate on the larger marshes and lakes. From these staging locations, they frequently feed on the shorelines or fly to large open expanses of grass to forage. This explains the significantly lower number of complaints in fall compared to summer (94% vs. 5%), and the shift from residential sites, the most common brood-rearing period complaint type, to golf courses, athletic fields, and airports. Winter reports are even lower (<1%), undoubtedly because most (>95%) of the birds migrate in late fall and the wetlands are frozen and snow-covered.

The birds' mobility combined with a preference for feeding sites where the existing landscape is essential for the intended human use, severely limits the potential for habitat modification. Gosser et al. (1997) recommended planting tall-growing trees to obstruct the birds' flight paths into problem sites. Indeed, the presence of trees surrounding many of the small wetlands used during the flightless period may be the reason that geese discontinue using small wetlands once they can fly. Trees conflict with human activities at airports, ball fields, and golf courses. Moreover, expanses of grass such as fairways and open water often serve as landing and take-off zones from which the birds walk or swim to the feed areas. Alternatives to goose-palatable grasses at airports have been investigated (Austin-Smith and Lewis 1970; Smith 1976), but no plant species have been identified that meet airport runway constraints: low height, low maintenance, relatively non-flammable, not attractive to other wildlife, etc. Overhead wire grids preventing geese from landing on a pond have successfully reduced use, but also precluded recreation such as fishing, swimming, boating, etc. (Lowney 1995) and impact non-target large birds such as herons, egrets, etc. Garner Lee Limited (1997) suggested that covering pond surfaces with floating "bird" balls could be highly effective, but also pointed to significant impacts on other wildlife.

LANDSCAPE MODIFICATION AND HUMAN BEHAVIOR

Human acceptance is a prerequisite to habitat modifications for goose redistribution or long-term control. Ironically, the open vista favored by geese is also a primary landscape component preferred by humans. Ulrich (1983) listed a moderate to high level of visual depth and a low or absent threat level as two of six primary attributes of landscapes favored by humans. Orians and Heerwagen (1992) contend that people "prefer environments in which exploration is easy and which signal the presence of resources necessary for survival," and where the likelihood of detecting danger in the form of "predators or unfriendly conspecifics" is high. Research on human landscape preference strongly indicates that savanna-like environments with water are consistently chosen over other environments (Balling and Falk 1982; Ulrich 1983, 1986; Orians and Heerwagen 1992), and that the preference was independent of age and cultural background, thus suggesting it may be innate (Orians and Heerwagen 1992). The decision to enter a landscape is also known to be high affective—emotionally based (Zajonc 1980; Ulrich 1983), and to be based on the level of apprehension (Orians and Heerwagen 1992). Clarke and Mayhew (1980), Bennett and Wright (1984), Michael and Hull (1994), and others investigated interrelationships between urban vegetation and crime, finding that surveillance, concealment, escape, and prospect were highly relevant components. Park areas with open visibility discourage criminals, whereas densely vegetated patches provide sites from which the perpetrator can scan undetected for victims, commit the crime, and escape. Michael and Hull (1994) recommended that parks and residential areas be designed or altered to maintain open sight corridors by pruning or removing eye-level vegetation near paths, roads, parking lots, buildings, picnic grounds, etc. They pointed to "thin strips of tree and shrubs separated by grass or low vegetation" as a design that would minimize the "maze-like quality of dense plants that obstructs surveillance and hinders pursuit."

These findings suggest that proposals calling for the wide-scale replacement of expanses of mowed bluegrass lawns in the Metro would be met with strong public concern. While extensive reshaping of existing Twin Cities or other urban landscapes has not been undertaken for goose management, the outcome of a Minneapolis 1995 lawn mowing policy change elicited responses in agreement with Orians and Heerwagen's general hypotheses. In this case, in order to lower costs and sediment input to nearby lakes, the Minneapolis Park and Recreation Board reduced grass mowing on sections of several parks. Public reaction was strong and negative. The Minneapolis City Council threatened to cite the Park Board for violating the city's grass height restriction ordinance (Daiz 1995). A "Citizens For Mowing Our Parks" group was formed and lobbied for a change in the Minneapolis City Charter to give the City Council the power to direct the Park Board to cut the park grass. No changes were made in the Minneapolis Charter, but the mowing resumed and the proposal was shelved.

COSTS

The author estimated the cost for those habitat modification techniques with the potential for extensive application, i.e., replacement of blue grass on shorelines and fencing. To assess costs relative to budget, the City of Plymouth, a rapidly growing suburb of 57,000 residents located 9 km west of Minneapolis, was selected as a study case. Plymouth citizens have complained about goose damage at 19 individual wetlands or lakes, ranging in area from 5 to 432 ha. Aerial photos (Twin Cities Metropolitan Council, 1:800 scale, flown in 1997) were used to determine the expanse of shoreline that would need to be replanted to non-turf, the length of fence needed to enclose the complaint site wetlands, and extent of goose nest habitat within the wetlands. Existing wooded shorelines were assumed to be sufficiently dense to deter geese, and omitted from the revegetation calculations but not the fencing computations. Cost estimates were attained from local landscaping firms and include materials and installation but not design costs. Two alternative vegetations were included in the cost estimates, tall grass prairie and ground juniper. Tall grass prairie was selected because it is the native plant community most often re-established in the Twin Cities. Except in special cases (see above) it is not known to be used for grazing. Ground juniper, if planted at a minimum spacing of 1 m, would provide near 100% ground cover, and yet, remain low (<1 m) enough to provide human visibility without pruning. Fence height was set at 0.75 m and chain-link material with a pipe top crossbar were specified. This height will thwart flightless goose movement yet permit most humans to step over safely. Contractors projected a 25-year fence longevity if placed in the upland and more frequent replacement if subjected to wave or ice damage, i.e., built below the high water level.

Plymouth goose complaint wetlands have 7 km^2 of open grass within 50 m of the shore and a total of 177 km of shoreline. Cost estimates ranged from \$0.54/m^2 for prairie, \$29/m^2 for juniper, and \$9.84/m for chain-link fencing; the total projected expenditures were \$3.7 million, \$203 million, and \$1.4 million, respectively. The 1997 City of Plymouth budget was \$15 million with \$10,000 allocated to goose management. Clearly, if Plymouth were to opt for the least expensive method—fencing—the city would have to spend 1/25th of total cost every year (\$56,000/year) to erect new or replace old fences. Also, the impacts on massive erections of low fences on other species of urban wildlife is unknown and needs study before such a program is undertaken. Expanses of cattail (*Typha* spp.) ranging from 0.009 to 1.1 km^2 were found in 74% of the 19 wetlands; thus, allowances for within-the-enclosure grazing would have to be done in order to avert gosling starvation.

If fencing were used to limit the Twin Cities brood-rearing carrying capacity to 25,000 geese, 93% of 1,331 km of shoreline currently in mowed grass or pasture would have to be enclosed at a cost of \$12.3 million. To replant this length of shoreline with prairie grass would cost \$33.9 million and for ground juniper \$1.8 billion. Using the population model for the Twin Cities (Cooper and Keefe 1997), 50% of the geese would have to be removed annually to attain population stability at 25,000. Goose removal costs are estimated at \$10/bird relocated and \$25/bird captured and processed for human consumption (Cooper and Keefe 1997); thus, expenditures from \$125,000 to \$312,500 per year would be necessary to control the population. Obviously, population management via direct removal is far less costly compared to the least expensive habitat modification.

SUMMARY

Canada goose populations and goose damage complaints are widespread in North American urban environments and growing. With a potential for impacting millions of human residents, and the ongoing conflicts over management approaches, urban geese present a major wildlife challenge. There is a critical need to evaluate promising techniques and integrate them into effective, comprehensive management programs. The control of goose damage by habitat modification, while potentially ecologically beneficial in urban settings, is biologically complex, expensive, and may be difficult to implement.

Because the species uses islands, muskrat lodges, man-made structures, and other elevated sites in semi-permanent and permanent wetlands for nesting, habitat modification options during the nesting period are limited to the simple, elimination of man-made nest structures, and the highly undesirable, filling or draining of the water bodies, and the elimination of islands.

Most (94%) goose damage complaints occur during the late spring and summer brood-rearing period when the birds are flightless; thus, habitat modification during this interval presents the greatest opportunity for limiting damage. Short-term applications where the objective is to reduce or eliminate goose use of specific property have the most promise. Proposed methods include: not fertilizing and mowing grasses, replanting lawns with rough grasses, ivy, shrubs, trees, etc., planting shoreline barrier strips of vegetation, and the erection of fences. However, there is a paucity of research on the efficacy, acceptability, and cost of these techniques.

The Canada goose appears adaptive and will use unmanicured grasses if alternatives are lacking. The bird also readily traverses dense vegetation in island environments with low mammalian predator densities, and observations indicate that the bird may behave this way in urban settings. Research on human landscape preferences strongly suggests a predisposition, like that of the Canada goose, for savannas with water bodies. Studies of the relationships between urban crime and vegetation shows a clear correlation between visual depth and risk; that is, dense visibility-obscuring plantings are associated with higher crime rates. Because crime is a crucial urban issue, public acceptance of widespread removal of turf is unclear. In light of these concerns, habitat modification recommendations in recent publications (Gosser et al. 1997; Grandy and Hadidian 1997), while stated as uncomplicated solutions, ignore critical application constraints, do not address long-term population management needs, fail to consider the potential for inhumane flightless goose starvation, overlook potential impacts on other urban wildlife, and do not address economic constraints.

Clearly, if habitat modification that limits Canada geese damage in urban environments can be accomplished humanely, without compromising human safety or landscape quality or the management of other wildlife species, and within fiscal constraints, then such programs would indeed be beneficial. However, significantly more research is needed before currently proposed methods can be deemed effective and environmentally sound.

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CONSERVATION IMPLICATIONS OF FERAL PIGS IN ISLAND AND MAINLAND ECOSYSTEMS, AND A CASE STUDY OF FERAL PIG EXPANSION IN CALIFORNIA

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ABSTRACT: Feral pigs (*Sus scrofa*) are an exotic ungulate which have been widely introduced worldwide with multiple ecosystem and economic consequences. The author conducted a semi-comprehensive literature review directed at identifying the current state of knowledge related to the effects of feral pigs on island and mainland plant and animal communities. Also, the author describes the situation in California where feral pigs that were introduced in the late 1700s are now widespread due to hunting-related introductions and natural range extensions. Feral pigs on predator-free oceanic islands are a serious conservation problem because they attain high densities and have contributed to near-extinctions and extinctions of multiple endemic plants and vertebrates. In mainland ecosystems, however, feral pigs can have both positive and negative effects depending on the local circumstances. Rooting, for example, can have both positive and negative effects on growth and survival of some trees, soils and soil processes, and the distribution of native and exotic grasses. In general, however, the negative effects of rooting by feral pigs are amplified when population densities are high. Feral pigs may compete with native species for limited resources, but there are limited data relevant to this hypothesis. Based on observations of small amounts of animal matter in their diets, feral pigs eat terrestrial vertebrates and eggs of ground nesting birds, but the importance of predation by feral pigs on native vertebrates is poorly known. Feral pigs also may have important indirect effects in mainland ecosystems by providing a new prey base for native predators which may then increase. In areas of Europe with extant wolf (*Canis lupus*) populations, wild boar (*Sus scrofa*) are an important prey species which may be facilitating numerical and geographic recoveries of wolves. Because wild boar are important prey for endangered Amur tigers (*Panthera tigris*), they are considered important for recovering tiger populations. In Australia, feral pigs are potentially important prey for dingoes (*Canis familiaris dingo*); whereas, in the United States, endangered Florida panthers (*Felis concolor coryi*) consumed 23% to 59% feral pigs, and mountain lions (*Felis concolor*) in Texas and California consumed 5% to 38% feral pigs. Research needs for feral pigs include quantitatively assessing: 1) how acorn foraging by feral pigs limits or influences regeneration of oaks (*Quercus* sp.); 2) the competitive effects of feral pigs on native species; 3) whether direct predation by feral pigs suppresses small vertebrate populations; and 4) how the availability of feral pigs as prey influences native predator populations.

KEY WORDS: *Sus scrofa*, predation, competition, rooting effects, distribution, California

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INTRODUCTION

The introduction of exotic species to new regions has generated much concern among conservationists and agriculturalists, because exotics can disrupt ecosystems and cause significant economic losses (Hone 1995; Morrison and Williams 1997). Once some exotics become established, they are difficult to eradicate except in small, localized regions or in island situations (Parkes 1990). In cases where it is not economically or logistically feasible to eradicate introduced species, it becomes necessary to focus management and conservation efforts on minimizing the ecosystem effects and economic damage by the organisms (Hobbs and Huenneke 1992).

Pigs (*Sus scrofa*) are a large ungulate native to Eurasia and North Africa which are now widely distributed as feral animals. Currently, wild pigs (wild boar or feral pigs) are found on all continents except Antarctica. The non-native distribution of wild pigs encompasses parts of North and South America, Central America, Australia, New Zealand, New Guinea, South Africa, and many oceanic islands (Kotanen 1995). Where populations of feral pigs are established, they can have important ecosystem and economic consequences. Ecosystem effects of feral pigs are related to the animals vigorously grubbing in wet or moist soil in search of acorns, plant bulbs/tubers, and small invertebrates (rooting), and direct predation. Negative economic effects of feral pigs result from the exploitation of row crops in agricultural fields by populations living in adjacent natural areas (Giusti 1993). Feral pigs in Australia also are important predators on domestic sheep (Choquenot et al. 1996).

Wild pigs are an extremely adaptable and generalized omnivore with a high reproductive output (two litters of five to six piglets per year) (Mauget 1991) and wide climatic tolerances (Lloyd et al. 1987). These characteristics result in feral pigs being very difficult to eradicate except on small islands or enclosed areas (Barrett et al. 1988; Katahira et al. 1993). Thus, in several countries where feral pigs are particularly numerous (Australia, New Zealand, United States), management efforts are directed at reducing, and then maintaining relatively low, wild pig densities in order to minimize their negative effects on ecosystems and agricultural areas (McIlroy et al. 1989; Choquenot et al. 1993). Although range expansion by feral pigs in some areas has ceased because of habitat limitations or intensive control programs (Clarke and Dzieciolowski 1991), the range extent of feral pigs in other areas continues to increase. In California, for example, feral pigs have recently expanded in distribution (Sweitzer et al. 1997a).

The author's objectives in this paper are threefold. First, to review the current state of knowledge related to the ecosystem-level effects of feral pigs to facilitate identifying key areas where additional research is needed. Second, to examine predator-prey relations among wild boar and their predators because very little is known of the implications of feral pigs as prey for native predators in Eurasia, and review what is known concerning predator-prey relations among feral pigs and several large predators in Australia and North America. Information on predator-prey relations involving feral pigs is important because increased prey availability may result in increased predator populations, thereby contributing to increased depredation on domestic livestock. Third, and finally, to describe aspects of the range expansion of feral pigs in mainland regions of California as a case study of management issues with the species.

METHODS

The author conducted a semi-comprehensive review of the scientific literature to identify the current state of knowledge on the potential effects of feral pigs on ecosystem properties. Undocumented statements regarding the multiple negative effects of feral pigs are found in many published accounts of feral pig biology. Thus, included in the review are only those studies which attempted to quantitatively examine different aspects of the effects of feral pigs on plant or animal communities. The author initially planned to include only peer-reviewed papers published in the scientific literature in the study. However, when reviewing proceedings from several symposia and some documents in the grey literature, useful information from several well-designed studies was found and included.

Data on range expansion dynamics for feral pigs in mainland California were drawn primarily from studies by Sweitzer et al. (1997a). Sweitzer et al. (1997a) used combined information from annual Hunter Game Take Surveys and hunter-killed wild pig tag returns to track range expansion by feral pigs and to delineate their distribution in mainland regions of California. Feral pigs also were introduced to the Channel Islands off the coast of southern California. The author compiled information on the history of feral pig introductions to the Channel Islands and described the extent and success of eradication efforts to subsequently remove the animals.

EFFECTS OF FERAL PIGS ON ISLAND ECOSYSTEMS

Feral pigs occur on many oceanic islands where their population densities frequently attain very high levels compared to mainland populations. On the Channel Islands of California, for example, feral pig densities commonly exceed 20 pigs/km^2 (Baber and Coblentz 1986; Sterner 1990) compared to on the nearby and ecologically similar mainland where densities of 3 to 4 pigs/km^2 are exceptional (Sweitzer et al. 1997a). On oceanic islands feral pigs have contributed to declines and extinctions or near-extinctions of endemic plants (Kastdalen 1982; Campbell and Rudge 1984; Challies 1975; Ralph and Maxwell 1984), seabirds (Stone and Scott 1984; Cruz and Cruz 1987), iguanid lizards (*Conolophus subcristatus*), giant tortoises (*Geochelone elephantopus*), and green sea turtles (*Chelonia mydas*) (McFarland et al. 1974; Green 1981). There were no studies that reported unequivocal positive effects of feral pigs on islands.

EFFECTS OF FERAL PIGS ON MAINLAND ECOSYSTEMS

The literature review revealed that numerous studies have examined issues related to rooting effects of feral pigs on mainland vegetation and plant communities, some have assessed changes in soil properties associated with rooting, but very few have directly examined issues related to interspecifiic resource competition, effects of acorn foraging on oak regeneration, or predation by feral pigs on native vertebrates. Below, the author describes the approximate state of knowledge related to these multiple potential effects of feral pigs.

Rooting Effects on Mainlands

In mainland situations the effects of rooting by feral pigs are variable and can sometimes positively influence ecosystems. Rooting by feral pigs on steep slopes may increase erosion (Schauss 1992), but on gentler slopes it can increase filtration and mobilize soil nutrients (Lacki and Lancia 1983; Singer et al. 1984). Rooting may reduce cover of herbaceous plants and shrubs and limit tree regeneration (Howe et al. 1981; Alexiou 1983; Bratton 1975; Lipscomb 1989; Becker 1985; deNevers and Goatcher 1990; Vtorov 1993), but can also enhance the growth of some trees (Lacki and Lancia 1986). Rooting in some areas has enhanced the spread of exotic grasses (Hone and Stone 1989; Spatz and Mueller-Dombois 1975; Vtorov 1993), but other research suggests it may increase the proportion of native annual and perennial plants (Aplet et al. 1991; Kotanen 1995; Lacki and Lancia 1983). Rooting may or may not alter or eliminate microhabitats for small rodents and amphibians (Singer et al. 1984; Lusk et al. 1993), and little is known of how this effects vertebrate populations. Also, it has been suggested by Work (1993) that rooting by feral pigs in California is ecologically equivalent to historically intensive rooting by grizzly bears (*Ursus arctos*) because of similarities in the appearance of grasslands and meadows rooted by the two species (Mattson 1997; Tardiff et al. 1997). Grizzly bears, which were historically widespread and very abundant in oak woodland habitats in California, were extirpated by the late 1900s. Ongoing research in Glacier National Park, Montana suggests that bear diggings in alpine meadows are qualitatively similar to rooting by feral pigs in wet meadows; grizzly bears repeatedly disturbed some areas, and plots disturbed by bears contained more plant species than undisturbed plots (Tardiff et al. 1997). Although the effects of feral pigs on mainlands varies, it is generally true that the negative effects of rooting are greatest when densities are high, which may explain the pronounced effects of feral pigs on islands.

Feral Pigs and Interspecific Competition

Feral pigs may have important effects on mainland ecosystems by diverting limited resources from native species (Barrett 1982). In Australia, for example, feral pigs root in mesic sclerophyll forests where they consume fruit bodies of hypogeous fungi (Claridge and May 1994). This is significant because fungal fruit bodies are a key resource for the endangered northern bettongs (*Bettongia tropica*). Laurance (1997) found that densities of northern bettongs were negatively correlated with feral pig rooting damage in wet sclerophyll forests, indicating that feral pigs are either in competition for fungal fruit bodies with northern bettongs, or northern bettongs avoid habitats damaged by rooting. Wherever acorn mast crops are available, feral pigs consume considerable amounts of the resource (Bratton 1975; Schauss et al. 1990; Bruinderink and Hazebroek 1996). It has long been considered that feral pigs compete with multiple species by consuming acorns and other mast crops (Barrett 1982), however, no studies have yet examined the hypothesis. In the oak woodlands of California, populations of feral pigs are strongly influenced by annual variation in mast production (Sterner 1990; Schauss et al. 1990). Although feral pigs consume considerable acorn mast, one alternative hypothesis is that feral pigs now consume a resource previously used by grizzly bears (Work 1993). In the 1800s, for example, grizzly bears were often observed in small groups beneath oak trees consuming acorns. Native Indians also harvested and consumed significant acorn mast. The extent to which feral pigs compete with native species for acorns, or whether they simply consume acorn mast previously used by other consumers remains unknown.

Feral Pigs as Predators

As generalized omnivores feral pigs are hypothesized to prey directly on reptiles, amphibians, and the eggs of ground-nesting birds (Henry 1969; deNevers 1993). Many diet studies reveal that feral pigs consume relatively low proportions of animal matter in their diets (Everitt and Alaniz 1980; Taylor and Hellgren 1997). However, reptiles and amphibians are occasionally observed in the stomachs of pigs (deNevers 1993), which they probably encounter when rooting in leaf litter or overturning ground debris. Systematic studies are needed to assess the importance of feral pig predation on regionally declining amphibian populations. Several studies have examined egg predation by feral pigs. Henry (1969) found that feral pigs "were a very minor nest predator" on eggs placed in dummy nests. Tolleson et al. (1993) noted that feral pigs will opportunistically consume eggs of ground-nesting birds, but it was not known if mortality was additive. In Australia, feral pigs may occasionally consume eggs from nests of the large, flightless Cassowary (*Casuarius casuarius*), an endangered ground-dwelling ratite (Crome and Moore 1990). Cassowaries have been in considerable decline due to loss of wet forest habitats in Australia. Research is needed to determine whether egg predation by feral pigs further threatens this endangered bird species (Crome and Moore 1990).

FERAL PIGS AS PREY FOR PREDATORS

Although a great deal of research has focused on the rooting effects of feral pigs, little is known of how the availability of feral pigs as prey may influence predator populations. This is important, ecologically, because predators can strongly influence prey populations by regulating population sizes and altering community structure (Mills and Shenk 1992; Estes 1996). Also, predators are of economic importance because they prey on domestic livestock and pets (Giusti et al. 1990; Bangs and Fritts 1996; Torres et al. 1996). The availability of feral pigs as prey may alter predator-prey systems and have a cascade of unanticipated indirect effects. For example, predator-prey theory predicts that generalist predators will switch to alternative prey (functional response) when the density of their primary prey declines (Taylor 1984). Because the functional response can stabilize or lead to increases in predator populations (numerical response), the introduction of alternative prey to an ecosystem may have large impact on predator populations in a region and, thus, a large effect on the ecosystem as a whole. In this section the author reviews what is known regarding wild boar and feral pigs as prey for predators to gain insight into how predator populations may respond to the availability of feral pigs.

Predator-prey Relations Among Eurasian Wild Boar and Their Natural Predators

Eurasian wild boar are an important prey species for extant wolf (*Canis lupus*) populations in Europe. Although wolves were historically widespread in Europe, they declined to extinction in most of the western and southern part of the continent by the end of the 19th century because of persecution and reduced availability of large ungulate prey (Okarma 1995); remnant populations of wolves remained in a few mountainous areas or isolated refugia in Spain, Italy, Poland, Asia and north and eastern Europe. In the last 20 to 30 years wolf populations in Europe have experienced numerical and geographical recoveries; in the early 1990s wolves expanded back into France from Italy (Poulle et al. 1997). With the exceptions of wild boar and roe deer (*Capreolus capreolus*), distributions of large forest ungulates in Europe [red deer/elk (*Cervus elaphus*), bison (*Bison bonasus*), moose (*Alces alces*)] decreased significantly due to habitat loss/conversion and hunting pressure (Okarma 1995). The current distribution of wild boar includes most of the species' historical range, as well as range extensions in parts of northern Europe (Saez-Royuela and Telleria 1986; Okarma 1995). Wild boar adapted well to agricultural development as evidenced by 70% to 90% crops (potatoes, grain, maize) in their diets when they occupy forest fragments adjacent to agricultural areas (Okarma 1995). The contemporary distribution of wolves in Europe overlaps completely with the contemporary range of wild boar. Diet studies from France, Italy, and Poland reveal that wild boar account for 7% to 53% of prey biomass for wolves depending on the availability of other wild and domestic prey (Mattiolo et al. 1995; Meriggi et al. 1996; Okarma 1995). Based on the consistent occurrence and importance of wild boar in wolves' diets, wild boar were probably important for maintaining viable wolf populations when they were in decline and may have facilitated recent recovery of wolves in parts of Europe. Also, in some areas of Italy, wolves prey heavily on livestock (Meriggi et al. 1996). Thus, one indirect effect of the availability of wild boar as prey for wolves in Europe may be increased predation by wolves on domestic livestock.

In a study of the endangered Amur tiger (*Panthera tigris*) in Russia, Miquelle et al. (1996) reported that elk and wild boar were key components of tigers' diets, together accounting for 84% of tiger kills. Wild boar individually were 20% of tigers' diets. Miquelle et al. (1996) recognized the importance of populations of forest ungulates for the conservation of the endangered Amur tiger and recommended that management programs actively work to maintain habitats and populations of wild boar and elk.

Feral Pigs as Prey for Dingoes in Australia

The dingo (*Canis familiaris*) is a widespread and common native predator in Australia where bounty programs are used to minimize predation by dingoes on livestock (Woodall 1983). In areas of Australia where feral pigs are uncommon, dingoes prey on kangaroos (*Macropus* sp.) rabbits (*Oryctolagus cuniculus*), and livestock (Thomson 1992). However, in Queensland, Australia where feral pigs are abundant and widespread, Woodall (1983) reported that feral pigs were important prey for dingoes. An index to dingo and feral pig populations based on bounty totals indicated that dingo populations closely tracked those of feral pigs and that feral pig numbers expanded and increased in local areas when dingo numbers were reduced (Woodall 1983). The author found no other published information discussing the importance of feral pigs to dingo populations in other areas of Australia.

Feral Pigs as Prey for Felids in North America

Feral pigs are now widespread in the southeastern United States, Texas, and California (Wood and Barrett 1979; Mayer and Brisbin 1991) where they co-occur with coyotes (*Canis latrans*), black bears (*Ursus americanus*), bobcats (*Lynx rufus*), and mountain lions. Of these potential predators of feral pigs, mountain lions may be the most important. Recent research has identified the importance of feral pigs as prey for the endangered Florida panther (*Felis concolor coryi*). Maehr et al. (1990) reported that Florida panthers consumed up to 59% feral pigs where panthers co-occurred with abundant feral pigs. Feral pigs in Florida were considered so important as prey for panthers that the feasibility of releasing feral pigs into the interior of the home ranges of individual panthers to augment their prey base was assessed (Maehr et al. 1989).

Research in Texas and California indicates that mountain lions prey on feral pigs in regions where feral pigs are abundant. Based on predator-kills and scat samples, Harveson (1997) determined that feral pigs constituted 28% to 32% of the diets of mountain lions in southern Texas.

Several studies in the Central Coast region of California indicated that mountain lions consumed 5% to 38% feral pig in their diets depending on the season (reviewed by Hopkins 1989). There are no quantitative data relating the availability and consumption of feral pigs by mountain lions to the dynamics of mountain lion populations in California. However, there is some evidence for a relation between expanding feral pigs and increasing mountain lion densities based on mountain lion depredations on livestock (Dick 1995; Torres et al. 1996) and Annual Hunter Game Take Survey data for feral pigs (Sweitzer et al. 1997a; CDFG unpublished data). Since 1972 when records on mountain lion depredation incidences begin, lion predation on domestic livestock has gradually and then more rapidly increased. Based on analyses of Annual Hunter Game Take Survey data, feral pigs expanded significantly over the same time period (Figure 1). A correlational analysis of the county level expansion by feral pigs and increasing numbers of mountain lion depredation permits issued by CDFG for counties in which feral pigs were present revealed a positive and significant correlational relation between expanding feral pigs and increasing mountain lion depredation incidences (Figure 1; Pearson correlation coefficient = 0.95, Bartlett's c^2 statistic = 20.08, d.f. = 1, P <0.001).

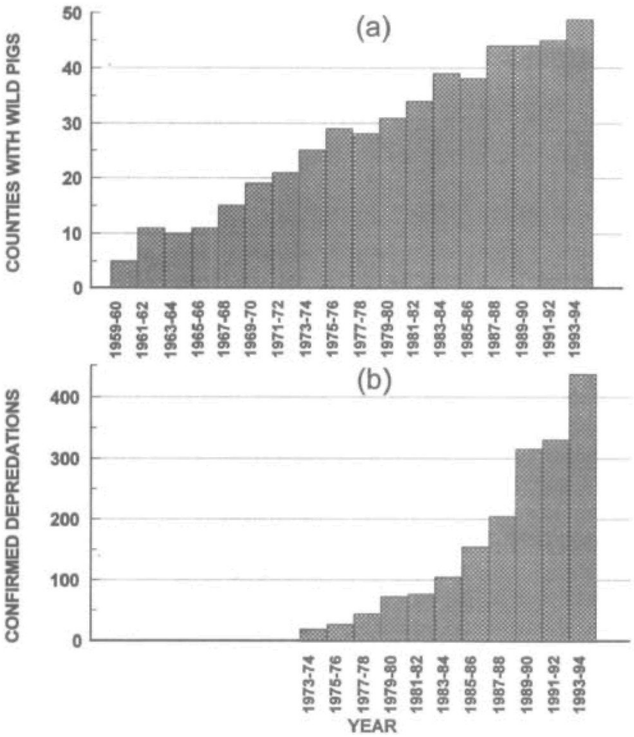

Figure 1. County level range expansion by feral pigs during sequential two year periods from 1959 to 1994 (a), and confirmed mountain lion depredation incidences from 1973 to 1994 (b). Numbers of mountain lion depredation incidences were included only for those counties in which feral pigs were considered present (hunted during at least one year during each two year period) during the same two year period.

Also, preliminary data from work by the research group directed at reconstructing diets of mountain lions based on concentrations of stable isotopes of carbon and nitrogen in the tissues of lions and their prey (see Ben-David et al. 1997 for details) suggest that several mountain lions in the North Coast region of California (where wild pig densities are >2.0 per km^2) included around 45% feral pigs in their diets (Figure 2). Based on increasing predation by mountain lions on livestock and increased frequencies of human-lion encounters, it has been suggested that mountain lion populations are increasing in some parts of California (Torres et al. 1996). It is not known yet whether this phenomena is directly related to the expanding and increasing number of feral pigs.

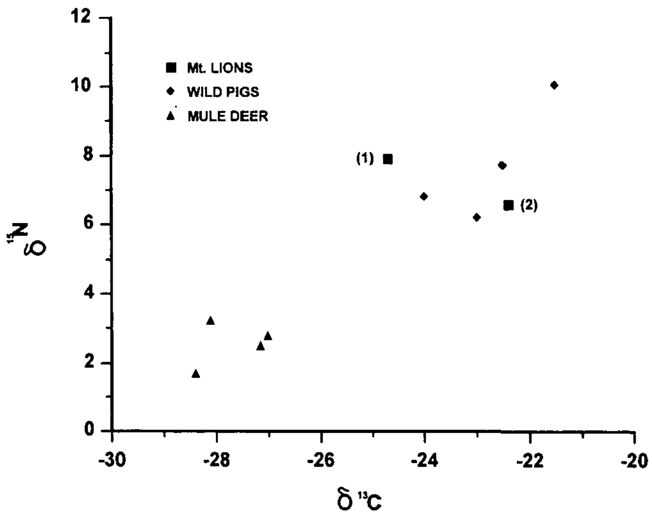

Figure 2. Values for $\delta^{13}C$ and $\delta^{15}N$ from preliminary analyses of muscle tissue of mountain lions, wild pigs, and mule deer from the North Coast region of California. Stable isotope signatures of wild pigs and mule deer are significantly different in bivariate space ($P < 0.001$ K nearest-neighbor randomization test; Rosing et al. 1998). Stable isotope values suggest that mountain lion 1 consumed 31% wild pig and 69% mule deer; whereas, mountain lion 2 consumed 43% wild pig and 57% mule deer, based on isotope ratios of wild pigs and mule deer and fractionation processes analyzed in a multi-source mixing model (Ben-David 1997b).

CASE HISTORY OF RANGE EXPANSION BY FERAL PIGS IN CALIFORNIA

The history of feral pigs in California begins with Spanish exploration and settlement in the 1600s and 1700s. Feral pigs were introduced to many of California's Channel Islands, but have been successfully eradicated from several of the islands in recent years. Feral pigs in mainland California have spread significantly since first being introduced. Due to the rugged topography, dense forests, and thick vegetation characteristic of feral pig habitats, however, eradication of feral pigs from extensive areas on California's mainland will probably be impossible. Below the author details the history of feral pigs on the Channel Islands and mainland of California, including details on disease and management considerations not already discussed.

Feral Pigs on the Channel Islands of California

Historically, no large native grazing animals occurred on the Channel Islands off the coast of southern California. Several ungulates including feral pigs were introduced to the four largest islands in the Channel Island archipelago (Santa Cruz, Santa Catalina, Santa Rosa, San Clemente) historically. The earliest introduction dates are poorly known, but feral pigs were established on Santa Cruz and Santa Rosa Islands by the 1700s, associated with Spanish explorations and a Spanish penal colony (Mayer and Brisbin 1991). Feral pigs were introduced to both Santa Catalina and San Clemente Islands in the early 1900s (Mayer and Brisbin 1991). Multiple efforts have subsequently been undertaken to reduce the impact of feral animal populations on the ecosystems of Santa Cruz and Santa Catalina Islands. Feral pigs were successfully eradicated from San Clemente and Santa Rosa Islands in 1980s and early 1990s, respectively (Long 1993). Several attempts to eradicate feral pigs from Santa Cruz and Santa Catalina Islands have so far proven unsuccessful (Sterner and Barrett 1991; Garcelon et al. 1993). However, an intensive eradication program from 1995 to 1997 successfully removed nearly all of the feral pigs from a 38 km^2 fenced area of the western portion of Santa Catalina Island (Garcelon, pers. comm.) Feral pigs are opportunistically killed on Santa Cruz Island but no organized eradication programs are underway there.

Feral Pigs in Mainland California

Feral pigs were first established in coastal regions of California in the 1700s from domestic stock free-ranged to forage in oak woodlands around early Spanish settlements (Barrett 1978; Pine and Gerdes 1973). Subsequently, Eurasian wild boar that were released in Monterey County in 1925 spread and interbred with the already present feral pigs to produce hybrid feral pig-Eurasian wild boar populations (Hoehne 1994). Although feral pigs were well established in California in the 1800s, their range extent was limited to fewer than 10 counties in coastal regions until the 1950s (Mayer and Brisbin 1991). In 1956, however, feral pigs were officially designated a game mammal whereupon numerous ranchers and landowners introduced them to their properties to establish populations desirable for fee-hunting (Barrett 1993). Multiple hunting-related introductions combined with natural dispersal has precipitated significant recent expansion by feral pigs. By the early 1980s, some 80,000 feral pigs had expanded to over 30 of California's 58 counties (Mansfield 1986), and in 1996, approximately 133,000 feral pigs occupied parts of 49 counties (Sweitzer et al. 1997a). Because feral pigs are adaptable and appear to be expanding into habitats/areas not previously considered suitable, feral pigs may continue to expand and increase in some parts of California where population densities are currently low (Sweitzer et. al. 1997a).

Hybridization between already present feral pigs and landowner-introduced Eurasian wild boar type feral pigs in some parts of the state in the 1950s and 1960s may have contributed to the accelerated post-1950s expansion of feral pigs. Due to hybrid vigor, hybridized Eurasian wild boar-feral pig type feral pigs may have experienced enhanced adaptive abilities which allowed them to expand into less suitable habitats. Little is known about the population genetics of feral pigs in California, but the author is currently using mitochondrial DNA techniques and analyses to examine this hypothesis.

Livestock and Zoonotic Diseases of Feral Pigs in California

Sweitzer et al. (1997a) screened multiple populations of feral pigs in California for a variety of livestock and zoonotic diseases. Results from their work suggest there are relatively few areas in California where moderate to high density feral pig populations overlap with important domestic swine producing areas. Also, no confirmed evidence of pseudorabies, and isolated instances of brucellosis exposure, suggest that feral pigs pose relatively low risks for infecting domestic swine with these important livestock diseases (Sweitzer et al. 1997a). Feral pigs in mainland California do harbor several zoonotic diseases (trichinosis, toxoplasmosis, leptospirosis, sylvatic plague) (Clark et al. 1983; Sweitzer et al. 1996), indicating that hunters should take necessary precautions when field-dressing animals to minimize exposure to blood. Also, and of potential importance for public health, Atwill et al. (1997) reported that feral pigs shed both *Cryptosporidia parvum* oocysts and *Giardia* sp. cysts in their feces. To the extent that these two microorganisms in feral pig feces are directly deposited or carried into municipal water supplies by overland flow, feral pigs may pose a risk of causing gastrointestinal illness among immune-suppressed individuals who drink from contaminated water supplies (Atwill et al. 1997). Additional and more widespread screening of feral pigs for livestock and zoonotic disease will help refine our knowledge of disease risks associated with feral pigs in California.

Management of Feral Pigs in California

The recent range expansion and increased levels of rooting damage caused by feral pigs has led to acrimonious debate regarding the management status of the species. The principal management objective of CDFG for feral pigs has been to control populations by hunting while simultaneously allowing landowners to remove feral pigs causing property damage after obtaining permits (Waithman 1995). However, some constituencies feel that feral pigs are a pest and should be subject to removal without special permit arrangements (Tietje and Barrett 1993). Related to these issues, Sweitzer et al. (1997a) noted that hunting may be effective in controlling feral pig densities on public and private lands in California where hunting pressure is high. However, feral pig numbers can be very high in unhunted parks or on private lands/ranches with limited hunter access. The result of localized regions with high densities of feral pigs has been increasing human-wild pig conflicts, debate over the efficacy of hunting to manage feral pigs, and calls to abolish already liberal hunting regulations to facilitate attempts to eradicate feral pigs. In another paper presented at this 18th Vertebrate Pest Conference, Doug Updike reviews changing management approaches with feral pig populations related to recently enacted legislation making it easier for landowners and others to remove feral pigs causing damage to private property, agriculture, and natural areas.

SUMMARY

Feral pigs on islands have multiple negative effects on plant and animal communities and should be eradicated whenever possible. In mainland situations, feral pigs can have both positive and negative effects depending on population densities. Future research on the rooting effects of feral pigs should focus primarily in regions where population densities are highest. Very little is currently known about the effects of feral pigs as competitors or predators. Additional research is needed in these areas, particularly where feral pigs overlap with threatened or endangered plants and animals. Finally, because predators can have important ecosystem and economic effects, research examining the significance of feral pigs as prey for native predators will help determine whether expanding feral pigs are contributing to increased predator densities and higher levels of livestock predation. Also, high numbers of predators supported by feral pigs may prey on native prey species at unusually high rates, thereby precipitating declines among those species (Sweitzer et al 1997b).

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TRACING THE HISTORY OF BLACKBIRD RESEARCH THROUGH AN INDUSTRY'S LOOKING GLASS: THE SUNFLOWER MAGAZINE

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ABSTRACT: The Sunflower magazine, the voice of the National Sunflower Organization, featured articles in January 1978 and December 1996 that began with these words, "If Old King Cole was a merry old soul, it was probably because he had only four and twenty blackbirds to contend with, and they were all out of commission!" This quotation captures the sentiments of sunflower growers, who have identified blackbirds as a major production problem since the 1960s. The National (formerly Denver) Wildlife Research Center, a unit within the U.S. Department of Agriculture's Animal and Plant Health Inspection Service Wildlife Services, is charged with both improving and developing new methods for managing blackbird damage to sunflower. The Sunflower has chronicled these research efforts championing studies with clear objectives and opposing studies, sometimes vehemently, that use resources for seemingly esoteric research. In this paper, the history of blackbird research in the northern Great Plains is traced through The Sunflower.

KEY WORDS: avicides, blackbirds, cattails, cattail management, crop damage, DRC-1339, National Sunflower Association, pyrotechnics, repellents, sunflower, The Sunflower, *Typha* spp., wetlands.

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INTRODUCTION

Hordes of marauding blackbirds rise from the sunflower field as a well-known South Dakota sunflower grower ignites a salvo of Class B pyrotechnics and quickly follows this barrage with several bursts from a .223 caliber semiautomatic rifle. A scene from the early 1970s, when the fledgling sunflower industry is just beginning to compete in the world oil markets? Amazingly, this event was witnessed by the senior author in the 1990s, at a time when other pest problems associated with cultivating sunflower, such as weeds and insects, had been mitigated by well-researched, economically viable management tools.

Despite millions of dollars spent on research and operational programs over 25 years, the "blackbird problem" remains to be solved. In 1994, 37% of sunflower growers still considered blackbird damage one of the three worst production problems in South Dakota, while 36% and 17% felt the same in North Dakota and Minnesota, respectively (Lamey et al. 1995). Further, as articulated through The Sunflower, the U.S. Department of Agriculture's (USDA), Wildlife Services unit (formerly Animal Damage Control) has yet to establish a reliable integrated pest management program. Nevertheless, the authors believe the National (formerly Denver) Wildlife Research Center (NWRC) and its cooperative research entities have made progress, perhaps significant progress, toward developing methods for managing blackbird damage to sunflower. In this paper, the authors support their thesis with information published in The Sunflower magazine.

The Sunflower, published by the National Sunflower Association (NSA), has a circulation of approximately 22,000 (Lilleboe 1995a). The magazine serves as an information outlet for about 18,500 sunflower growers, with 13,300 of these growers in the northern Great Plains (National Sunflower Association, unpublished data). Since its inception in 1975, The Sunflower has published 27 issues containing 31 articles on the prevention of sunflower damage by blackbirds. Many articles were penned by Don Lilleboe, who was editor of the magazine until 1987, and is now a contributing writer and editor. Larry Kleingartner, the Executive Director of the NSA, has taken over the editorial chores since 1987 and authors many articles for the magazine.

ARTICLES

Anonymous, 1978a, Growers, Research Personnel Seek Blackbird Solution

This article begins with "If Old King Cole was a merry old soul, it was probably because he had only four and twenty blackbirds to contend with, and they were all out of commission!" Sunflower growers are investing an average of $5.00/acre ($12.35/ha) to control blackbird damage, but to no avail, as birds took an average of 8 to 10% of the crop, with some growers suffering heavier losses. Against this backdrop, the most prominent question from sunflower growers is how to dramatically reduce blackbird populations. However, the U.S. Fish and Wildlife Service (USFWS), in charge of developing damage abatement methods, is focusing on: 1) improving methods for putting repellents on plants; 2) developing bird-resistant hybrids; 3) conducting taste aversion studies; 4) recommending land management practices; and 5) developing lure cropping strategies. Additionally, the basic feeding, breeding, and migratory behaviors of blackbirds are being studied.

In December 1977, a meeting is held at North Dakota State University (NDSU) among representatives of NDSU, North Dakota Sunflower Council, and USFWS. Biologists from the USFWS testify that heavy damage occurs under flightlines between roosts and loafing areas. They speculate that heavy losses occurred in 1977 because of: 1) an abnormally long damage season (75 compared to 45 days); 2) an early small grain harvest that resulted in waste grains being buried by fall plowing; and 3) more fields planted near wetlands. Industry representatives express doubt that current methods of scaring birds such as propane boomers, guns, and chemical repellents are effective and that reducing the blackbird populations would be more appropriate. USFWS biologists explain that numerical reductions are not always accompanied by an equal reduction in depredation. Nevertheless, they suggest poisoning blackbirds in the roosts, placing avicides at bait stations, and developing chemosterilants as three possible avenues of research. Meeting attendees recommend: 1) research on chemosterilants for male blackbirds be expedited; 2) development of more effective approaches for distributing damage abatement information; and 3) funding from Congress be sought to enhance the blackbird-research effort.

Anonymous, 1978b, Australians Have Bird Problems Too

The Sunflower consoles U.S. sunflower growers, just beginning their annual battle with blackbirds by relating the hardships endured by growers in northern Australia. Apparently, cockatoos, white over-sized parrot-like birds, were observed harvesting sunflower at a rapid rate; however, damage statistics are not available.

Pfeifer, 1979, Plan Ahead For Blackbird Control

Pfeifer, State Director for the North Dakota Animal Damage Control program, suggests that to maximize sunflower yields growers should plan on controlling all pests, including blackbirds. He advises growers to: 1) avoid planting fields near cattail (*Typha* spp.) marshes; 2) synchronize sunflower plantings because early and late fields suffer the most damage; 3) provide lanes planted with an early maturing crop for easy access to blackbirds feeding in large fields; and 4) provide alternate foods on conservation set-aside land where the birds can feed undisturbed.

Anonymous, 1979, Researchers Seek Long-Term Answers to Blackbird Problems

Sunflower growers near cattail marshes along major flyways know about blackbird damage. In 1978, blackbirds destroyed more than 1% of the sunflower crop, valued at $2.75 million. Yet, the only agricultural solutions are to plant early-maturing hybrids and to avoid planting near cattail marshes. Chemical repellents and scare devices, such as propane boomers, guns, and electronic alarm calls may help rid one sunflower producer of birds, but passes the problem along to another grower.

NDSU researchers are looking for solutions to blackbird damage with funding administered through the U.S. Department of Interior. Most of the funding is designated for bird-resistant hybrid development, but developing these hybrids is predicted to take several years. Studies on food aversion, food habits, migratory behavior, alternative food sources, cultural practices, and associated environmental factors consume the remainder of available funds.

Sandvik, July 1980a, Season For Blackbirds Approaches - Millions $$$ Damage in '79

Sandvik interviews three USFWS biologists on their views concerning blackbird damage to sunflower. The USFWS is testing variations of old methods such as hawk kites, jump-up scarecrows with distress calls, and trying to improve the efficacy of the avian repellent Avitrol® (active ingredient - 4-Aminopyridine). The USFWS determines sunflower damage in North Dakota, Minnesota, and South Dakota to be 0.88%, 0.69% and 0.58%, respectively. Of the 575 fields surveyed by the USFWS, 95% have estimated damage less than 3%. At a seed value of $0.09/lb ($0.20/kg), about $5.0 million of sunflower is lost to birds. Counties in North Dakota with the most damage are Benson, Bottineau, McHenry, Pierce, Grant, and Emmons; whereas, Mahnomen and Traverse counties in Minnesota, and Moody, McCook, and Hanson Counties in South Dakota suffer the highest losses in these states. The USFWS reports that these counties have an abundance of cattail marshes, the preferred habitat of roosting blackbirds. Moreover, increased sunflower acreage in western North Dakota may have drawn blackbirds to an area that normally does not have significant damage.

The USFWS believes that increased sunflower acreage does dilute the overall blackbird damage but blames the drought in the northern Great Plains for high damage in localized areas. Drought, which effectively reduces the number of prime roosting sites for blackbirds, ironically concentrates the birds and creates situations where heavy local damage occurs. Referring to blackbirds, one biologist is quoted as saying "They don't live to eat; they eat to live. And in the process, they're going to take those foods that rate best in taste, nutrition, and availability." He concludes by saying that if you plant near prime roosting and loafing habitat, you can expect problems, especially during dry years.

Sandvik, 1980b, Three Methods of Battling the Birds

Sandvik interviews three people familiar with the blackbird-sunflower problem to find out what they are doing to control damage. An owner of a flying service believes Avitrol®, which causes birds ingesting the 1-in-100 treated corn particles to emit distress calls, is effective if applied early in the damage season. He adds that birds have difficulty finding the baits in weedy fields. A grower from Westhope, North Dakota plants sunflower in the same field three years in a row knowing he would have bird problems. In 1977, he uses a .22 rifle and propane boomers; in 1978, a helicopter is used to chase birds, and in 1979, he purchases six hawk kites attached to helium-filled balloons. This grower concludes that one hawk kite controls birds as well as a propane boomer, but hawk kites are more work.

The last interview showcases an innovative farmer who uses Avitrol® but has mixed results. So he equips his helicopter with a cassette tape deck, speakers, and amplifier and plays "Willie Nelson Live in Concert." At times, he augments this method with a couple of riflemen on the ground. After dark, this grower and some of his friends canoe into the roosts and throw pest bombs and shoot into the birds. He feels that all methods of blackbird control are partially effective, but methods of harassment must change periodically. He is quoted as saying, "An explosion every 15 minutes just doesn't do it."

This paper has been peer reviewed.

Besser and Otis, 1980, Dakota Drought Speeds Blackbird Decline

Besser and Otis of the USFWS's Denver Wildlife Research Center report that red-winged blackbird (*Ageliaus phoeniceus*) numbers dropped from 2.2 million in 1965 to 1.1 million in 1980 in a 30,000 square mile (77,694 km^2) area centered on the James and Souris Rivers from Canada to central South Dakota. They speculate that modern large machinery has enabled growers to plow the drier parts of wetlands normally used by nesting redwings. Besser and Otis say that a decline in blackbird numbers during drought years may not necessarily result in lower damage, because nonbreeding blackbirds may congregate earlier, and with fewer suitable roosting locations available, damage in some areas may be abnormally high.

Anonymous, 1980, Bird Research Project Continues

NDSU scientists report that bird damage may be highest in tall plants with head diameters of 4 to 8 inches (10.2 to 20.3 cm). Heads outside this range, with long bracts and down-turned, flat, or concave heads have the most promise for bird resistance. Finally, these scientists propose that certain naturally occurring chemicals may avert blackbirds from eating sunflower seeds and that further investigation is warranted.

These investigators show that blackbirds will feed in all directions from the roost, usually traveling up to five miles (8 km) from the roost; however, some birds may travel up to seven miles (11.3 km) to feed. Birds appear to cause more damage in weedy fields; weeds make it harder for the birds to find treated grain baits, such as Avitrol®. Taste aversion studies show that developing a delivery system to educate blackbirds not to eat sunflower will be difficult. Investigators were hoping that birds would retain an aversion for sunflower when feeding in other locations.

Fairaizl, 1982, Springtime Blackbird Control Measures

Fairaizl, a Wildlife Biologist with the USFWS's ADC, advises farmers to: 1) avoid planting near cattail marshes and shelterbelts; 2) synchronize planting in a given area because the first and last fields to mature tend to suffer the most damage; and 3) leave lanes in the fields for Avitrol® baiting and easy access for placing scare devices. The loss of field production from providing access lanes, he continues, is partially negated by plants with bigger heads and more seeds. Finally, Fairaizl suggests planting alternate foods on conservation set-aside acres to serve as lure crops.

Kleingartner, 1982, Blackbird Population Control Essential

Kleingartner, Executive Director for the NSA, provides a litany of blackbird transgressions: Blackbirds annually damage $5 to 12 million in sunflower, $15 to 25 million in ripening corn, $20 to 50 million in seeded corn, $10 million in ripening cherries, $6 million in sorghum, $2 to 5 million in rice, $4 million in grapes, $1 to 2 million in blueberries, $1 million in lettuce, and unknown dollars of cereal grains, peanuts, and pecans. Moreover, blackbirds are attracted to feedlots where they eat and contaminate feed and water. Finally, blackbirds cause health hazards, such as histoplasmosis, and are a nuisance in southern cities during the winter. Kleingartner concedes that blackbirds do have some value because they eat weed seeds and insects.

The Denver Wildlife Research Center (DWRC) reports that research is progressing on baits and repellents, scaring devices, lure-crop plantings, and bird-resistant hybrids; however, the NSA counters that dispersing blackbirds only transfers the problem from one farmer to another. Researchers believe that data on migration patterns and roosting habits may be a key aspect in identifying the blackbird's vulnerabilities, which could then lead to a more effective population control effort. DWRC's development of a new paint-tagging method leads to a clarification of migration patterns, showing that redwings funnel from northwestern Missouri to sunflower growing areas in the Dakotas, Minnesota, and Canada.

Kleingartner maintains that population control can be accomplished in Missouri with chemical sterilants and toxicants. He reports that growers do not want to eradicate the blackbird, but want some form of population control. Sterlization of males and lethal control of females seem like promising methods to the NSA. While Missouri may be the vulnerable staging area, population suppressants will require intensive testing of safety hazards to humans and nontarget species, a long and costly process. Regardless, Kleingartner believes the time to start is now, because the political climate is right, and the NSA has allies in other commodity groups who have similar goals. He concludes that growers feel the USFWS will not pursue population control as a matter of agency philosophy; moreover, the blackbird problem is directly related to inaction by the USFWS. An aggressive and sincere effort by the USFWS to reduce blackbird numbers would improve their image with growers, and to quote the Executive Director, "would also be a big step in reducing the problems growers have with blackbird damage."

Anonymous, 1982, Mesurol® To Be Tested On Birds

South Dakota State University (SDSU) researchers obtain a Section 18 EPA label for testing Mesurol® for blackbird control. Mesurol®, an effective bird deterrent for other crops, will be formulated on cracked corn at 0.5 lb (0.23 kg) per 100 lb (45.4 kg) corn and applied by air on 3,000 acres (1214.1 ha). Mesurol® has already been tested on sunflower as a foliage and head spray but is not effective because the downward-facing head position keeps the spray from contacting the achenes.

Lilleboe, 1983, Bird-Resistant 'Flowers Now Being Field Tested

Lilliboe leads this article with "Will the day ever come when hungry blackbirds fly past maturing sunflower fields rather than diving in for a hearty meal?" NDSU scientists plan to plant bird-resistant sunflower on 20 farms in North Dakota, Manitoba, and Ohio to answer that question. They are convinced that plants with long head-to-stem distances, flat or slightly concave downward- facing heads with long bracts, and tightly-held achenes may provide substantial bird resistance. Theoretically, bird-resistant sunflower are too expensive

This paper has been peer reviewed.

energetically for birds to pursue, forcing them to seek alternate sources of food, such as weed seeds and waste grains. However, current genetic lines of bird-resistant sunflower, with 10 to 20% lower yields and 5 to 10% lower oil than commercial hybrid sunflower, are not competitive in the seed market and need improvement. Purple-hulled sunflower also are being tested for bird-resistance because they contain high levels of anthocyanins that seem to impart a bad taste. NDSU scientists conclude that sunflower may never be totally immune to blackbirds, but theorize if birds are moved from susceptible locations near wetlands, the damage will be dispersed over a larger area.

Anonymous, 1984a, NSA Proposes Blackbird Program

The NSA proposes that Congress appropriate $25 million over a 10-year period to develop methods for reducing blackbird populations. Funded projects would lead to the development of chemosterilants and avicides that would be implemented by the USFWS on an operational basis. Progress and direction of the program would be monitored by a citizen advisory board.

The legislation, sponsored by the NSA, notes a 500-million blackbird population in North America, with the majority wintering in the southeastern U.S. The USFWS estimates that direct damage to food crops and feed grains is about $80 million; indirect costs incurred from controlling damage are unknown. The NSA maintains the most probable solution to blackbird depredation is to reduce their population, either by chemosterilants or lethal methods. From an environmental and moral position, chemosterilants appear to offer the best potential.

Arnett, 1984a, Blackbird Control in Sunflower

Arnett, Assistant Secretary for Fish, Wildlife, and Parks, U.S. Department of Interior, spoke to attendees of NSA's national meeting and provided comments to The Sunflower. A quote from Arnett sums up the USFWS' position on blackbirds, "The picture seems clear: if possible, do not plant sunflower near shelterbelts, marshes and other places where blackbirds roost." Arnett acknowledges there is no single panacea for controlling blackbird damage, and that a combination of methods are being developed to reduce blackbird problems to a tolerable level. Other USFWS research is focusing on the timing of blackbird damage. Arnett reports that sunflowers are most vulnerable when 10% of the yellow petals start to wilt; 41% of the damage occurs between the third and ninth day following this time. Bird harassment efforts, therefore, should be done early, before flocks develop a feeding pattern.

The USFWS is well aware that farmers have tried and are disappointed with the efficacy of Avitrol®. Scientists think Avitrol® failed because the chemical is lost during handling and is vaporized during hot weather; the manufacturer agrees to correct these problems. Arnett promises further research on increasing the efficacy of this repellent by finding baits that are more acceptable to blackbirds than cracked corn, such as sunflower. He then addresses the question of direct control at winter roosts in the southern U.S. by stipulating that, although it seems simple to growers, it is not a feasible approach for solving blackbird depredation to sunflower. The USFWS intends to focus its damage-reduction efforts closer to the time and place of occurrence. Arnett concludes, rather cryptically, the USFWS will take into consideration both the positive and negative values of blackbirds as viewed by the nation's citizens.

Fox, 1984, Bird Resistance Update

Fox, a sunflower breeder with NDSU, writes that although damage may be only 1 to 4%, the damage is localized and farmers planting close to wetlands receive more damage than other growers. Some of these farmers have been forced to abandon sunflower because the blackbirds severely damage an otherwise profitable crop. At this time, Fox has settled on studying morphological and chemical modes of bird resistance. He reports that morphological traits include flat or concave heads, long bracts that wrap around the head, horizontally-oriented heads, head-to-stem distance greater than 6 inches (15.2 cm), and tightly-packed achenes. These bird-resistant traits are maintained until a killing frost, after which the heads dry and the seeds loosen. Fox continues by touting purple-hulled sunflower, which contains high levels of anthocyanins that may advert birds from eating seeds. The anthocyanins levels are highest near maturity, and bird-resistance is greatest at this time.

In 1983, field tests show that poor growing conditions produced under-developed morphological traits for resisting bird depredation; this, combined with heavy bird pressure, resulted in severe damage in the test plots. Bird-resistant sunflower seeds still are 8% below normal in oil content and yields remain low. However, Fox still believes that a commercially acceptable bird-resistant variety can be developed.

Anonymous, 1984b, Blackbird Monies Being Voted On

The Sunflower notes that a $2.5 million request for chemosterilant and toxicant research on blackbirds has passed the U.S. Senate Appropriations Committee with support from sunflower-, corn-, and rice-producing states. The money will be directed to the USFWS. A citizen advisory committee will oversee the funding.

Anonymous, 1984c, Update on Blackbird Funding

A $2.5 million request for funding of chemosterilant and toxicant research fails in Congress. As a compromise, an additional $200,000 is added to NDSU's current research program on developing bird-resistant sunflower.

Anonymous, 1986, USDA Gets Blackbird Program

This article announces the transfer of the ADC program from the USFWS to the Animal and Plant Health Inspection Service (APHIS) of the USDA. The NSA supports the transfer and believes more progress will be made on controlling blackbirds with the USDA leading the research effort. Additionally, Congress at the behest of the NSA appropriates $500,000 for research on lethal and nonlethal methods of controlling blackbird damage to crops. Finally, the USDA begins developing a citizen advisory committee on blackbird control; the NSA will be represented on this committee.

Kleingartner, 1988, Progress Being Made on Blackbird Front

Kleingartner touts the development of a new toxicant for reducing blackbird populations. He reports the USDA is committed to evaluating CPT (3-Chloro-4-methylbenzenamine), a new avian toxicant. If research finds CPT to be effective and safe, the USDA will commit to gaining registration approval by the Environmental Protection Agency (EPA). Growers want an avicide, because there are too many blackbirds to control with just harassment techniques. Apparently, the USDA's ADC leadership agrees. Kleingartner recounts that CPT is closely related to DRC-1339, a chemical registered for controlling blackbirds and starlings in feedlots under the trade name of Starlicide®. A DWRC official relays to the NSA that CPT will be tested at two sites in the sunflower-growing region and at two winter roosts sites in the southeast. These tests will determine efficacy and gain necessary information for proceeding with obtaining a full EPA registration. However, this official warns that EPA clearance of CPT is not certain, and the most optimistic predictions of time-line and costs are several years and millions of dollars.

A North Dakota ADC spokesperson assures the NSA that an avian toxicant will make ADC's job of protecting sunflower from blackbirds easier, and he anticipates a substantial reduction in damage if a roost toxicant is registered. Aerial hazing of blackbirds is not the best solution but is ADC's only option at this time. He reports that flocks of resident birds congregating in August are impossible to move out of the sunflower production area. The President of the NSA, expresses optimism the USDA is a real partner at the federal level.

Anonymous, 1989, EPA Nixes Testing of CPT in the North

The USDA wants to field test CPT to determine its effectiveness before spending several million on research required for an Experimental Use Permit (EUP). The EPA will not allow testing of CPT on wetlands without an EUP but will allow testing on two terrestrial sites in the South in winter.

Kleingartner, 1989, Blackbird Controls Still On Front Burner

Kleingartner brings good news and bad news. The good news is the EPA allowed testing of CPT in a southern roost, and preliminary test results indicated the avicide was very effective. The bad news is the USDA cannot test CPT in a northern wetland without more data. Ongoing discussion with EPA regarding testing in the sunflower-producing region may result in some limited CPT testing in the North. Upon transfer of blackbird damage control from the USFWS to USDA, the ADC unit decides that a blackbird toxicant will be the number one research priority for controlling damage to crops and minimizing human health and safety concerns related to blackbirds. CPT offers the best potential as a toxicant because the chemical is highly toxic to blackbirds but only low to moderately toxic to mammals and predatory birds.

On another front, the USFWS stresses that while cattails are perfect for blackbird nesting and roosting, they are not conducive for propagating ducks. The USFWS advocates spring burning as the best method for controlling cattails but acknowledges that forced cattle grazing may also work to control cattail. As an example of how effective cattail management can be, a USFWS manager points to a wetland near Alice, North Dakota that contained 1,000 acres (404.7 ha) of cattail and harbored 5 million blackbirds before the cattails were managed. It now contains few blackbirds and numerous ducks. The USFWS is looking at purchasing a sickle bar mounted on an air boat for cutting cattail below the water line. Farmers can burn leased wetlands with prior approval from the appropriate USFWS district office.

Meanwhile, the aerial hazing program continues in 1989, despite many detractors. Hazing is not intended as a final answer says the incumbent NSA President. He continues by saying the NSA wants a federal commitment to deal with the problem.

Kleingartner, 1990, Blackbird Control Front Update

Kleingartner begins this article with, "Ever wonder how to get rid of some house guests who stayed too long? Get rid of the house." Blackbirds stay too long and eat too much, he continues, because they have cattails as an excellent habitat for nesting in spring and roosting in fall. Cattails make a comfortable home by protecting blackbirds from predators, bullets, airplanes, and inclement weather. Kleingartner informs his readers that controlling cattails may not eliminate blackbird problems, but it is a significant tool.

The promising addition to cattail management will be a toxicant that can be applied either by air or by ground application. The USDA is testing CPT, but the product is five years away from EPA registration because of a battery of expensive and time-consuming research requirements. USDA officials hope the reregistration of DRC-1339, currently underway, may provide some data for CPT registration. Meanwhile, NDSU continues working on a bird-resistant variety of sunflower and hopes to release the germplasm to private companies in 24 months. Kleingartner reiterates that a bird-resistant hybrid, while considered an important tool for reducing damage, is not the total answer.

The aerial-hazing program continues in 1990, though most participants agree it is just a band-aid. However, a survey of growers shows the hazing program is preferred over putting money into scare devices and cattail management. A North Dakota ADC manager decides to concentrate aerial hazing in high-damage areas. The same manager wants to test DRC-1339 grain baits in sunflower fields but needs a state emergency label.

Kleingartner declares that destroying cattails is the best answer for reducing sunflower damage. The USFWS is agreeable, stating they want to reduce blackbird numbers and increase duck abundance by managing cattails. Finally, the NSA is requesting federal funding for 1991 for cattail management. Farmers are urged to reduce cattail growth wherever possible.

Lilleboe, 1991, Cattail Management Helping Both Waterfowl & Sunflower

Lilliboe begins this feature article with "Other than the now-famous Patriot missiles, is there any weapon not used against feathered foes?" None of the myriad of techniques in use by growers, has yet to provide the protection from blackbirds they need. Bird-resistant sunflower does have promise as a management tool, but commercially viable hybrids are still years away. Growers are urged to use the best method available; at this time, it is cattail control. The consensus by all parties involved is that some cattails are good, but too many cattails will both destroy the wetlands for waterfowl and create blackbird roosting habitat. The USFWS is actively using cultural and mechanical means to manage cattails, declaring that they are not trying to eradicate blackbirds, just trying to move them south faster. The USFWS is aspiring for a 50:50 emergent vegetation to water ratio but initially will accept a 70% reduction in cattail. In 1990, the USFWS managed cattails on 1,700 acres (688 ha) in 63 wetland basins in North Dakota.

DWRC tested aerial applications of 3 qt/acre (7.0 l/ha) of Rodeo® herbicide in 1989 and 2.5 qt/acre (5.8 l/ha) in 1991 to control 70% of the cattails. DWRC, NDSU, and SDSU are conducting cooperative studies designed to test the effects of the herbicide applications on invertebrates, waterfowl, and water quality. The cost of aerially applying Rodeo® is about $64.00/acre ($158.00/ha). The lead researcher for DWRC emphasizes that blackbirds area management problem that each farmer must solve. The article concludes that cattail control is not a panacea but should be a part of an integrated management program used in combination with other management tools.

<u>Lilleboe, 1992, NDSU Develops Bird-Resistant Lines</u>

Lilliboe reports that NDSU scientists produced a bird-resistant sunflower and have now released two inbred genetic lines to commercial breeders. Sunflower varieties with horizontally-oriented concave heads and long head-to-stem distance are predicted to be the most effective against foraging blackbirds. Unfortunately, the released bird-resistant lines are susceptible to rust and downy mildews, and one line has higher yields and lower oil while the other line has the opposite attributes. The futures of these genetic lines depend on how big the potential commercial market will be for bird-resistant hybrids. Scientists did not believe that bird-resistant hybrids are the solution, but a component of an integrated pest management system.

<u>Anonymous, 1992a, Is a Cattail Herbicide For You?</u>

This article discusses the economics of using the aquatic herbicide Rodeo® for dispersing roosting blackbirds. A DWRC scientist maintains it is cost-effective to manage cattails. For example, if a 25-acre (10.1 ha) wetland harbors 20,000 birds and each bird consumes a half ounce (14.2 g) of sunflower/day, that flock will eat 617 lb (280 kg) of seed/day. Assuming a seed price of $0.10/lb ($0.22/kg), this flock consumes $61.70 worth of sunflower/day. Over a month's time, the dollar loss will be about $1,850. The cost of treating from 70 to 100% of the wetland is between $1,050 to 1,500; thus, the cost of treatment is recouped in one year.

In 1992, DWRC and NDSU researchers are gathering data on the efficacy of cattail management. Additionally, they are assessing the effects of Rodeo® on water quality, aquatic invertebrate populations, breeding bird populations, and winter cover for pheasants. Researchers continue evaluating the response of cattails to various application rates of Rodeo® herbicide.

<u>Anonymous, 1992b, Hazing Help Available for Blackbird-Plagued Dakota Producers</u>

In this article, sunflower producers with blackbird problems are urged to call North or South Dakota ADC for assistance. The aerial hazing program, developed by the NSA and ADC, is still in place to harass birds in sunflower fields. Growers are given telephone numbers to call if they have at least 1,000 blackbirds in a given field and are told to initiate their own scare tactics when birds are observed in sunflower. Growers are asked to provide legal descriptions of field locations, mark fields with white material, and give ground support with 22-caliber rifles, racket bombs, screamers, etc. Growers are urged to be careful not to shoot the airplane and report any wetland with more than 5,000 blackbirds to schedule for cattail-control measures.

<u>Lilleboe, 1992, South Dakotan Fires Back at The Blackbirds</u>

In this article, a Clark County, South Dakota sunflower grower explains how he disperses blackbirds from sunflower fields. He describes the development and use of Class B explosives that contain more than 55 grams of powder. These pyrotechnics were legalized by the "Boomer Bill" which was passed by the South Dakota legislature in 1992. This grower is convinced that explosives work when used in combination with propane cannons, taped distress calls, and a .223 caliber semiautomatic rifle. His annual costs for chasing blackbirds from mid-August to early October are about $2,500, including the use of at least four Class B explosives per day at $6 to 8 each. He is thinking about developing a radio-controlled airplane with an on board ignition system to detonate explosives within the flocks. Another idea is to connect a series of bombs throughout the field.

<u>Lilleboe, 1993, No Vacancy Sign Out For Blackbirds</u>

Lilliboe begins this article with "Bearing ill will toward the innocent cattail is like nurturing a grudge against motherhood and the flag." A USDA scientist says cattail management is a valuable ally for dispersing blackbirds. In cooperation with NDSU, the USDA is studying the impacts of cattail management on ring-necked pheasants (*Phasianus colchicus*), invertebrates, and water quality.

Scientists recommend that cattail management be used if 5,000 or more birds are using the wetland. Between August and the first frost, about 70% of the marsh should be aerially sprayed with Rodeo®, leaving strips of living cattail as cover for other wetland animals. To ensure a good control, an application rate of 2.25 qt/acre (5.3 l/ha) of Rodeo® at a cost $55.00/acre ($136/ha) is recommended. Growers are urged to only treat areas of the marsh that contain water because that is the preferred roosting location for blackbirds. Under these conditions, one treatment may last four years or longer.

Scientists point out that cattail management disperses birds but does not reduce the overall population. Each

This paper has been peer reviewed.

producer is urged to manage bird problems by dispersing the birds, and therefore the damage, over a wide-area. The article concludes the battle will be won if the 10% of the growers who suffer 10% or greater damage can reduce their damage to 1 to 2%.

Anonymous, 1995, So, What Was Bugging Your Crop Last Year

In 1994, a mail survey is conducted to discover the sunflower growers' most prevalent production problems in Kansas, Minnesota, North Dakota, and Minnesota. Of the 1,079 respondents, nearly 25% estimated losses of 5 to 10% to blackbirds; whereas, about 10% of the growers reported losses greater than 10%.

Lilleboe, 1995, Cattail Management Now Focus Of Blackbird Battle

Lilliboe chronicles the end of the blackbird-hazing program by ADC, the rise of cattail management, and offers hope for the development of an avicide. Besides boomers and other scare devices, cattail management is now the only game in town. With several years of research in hand, the NSA board recommends that ADC switch its funding from aerial hazing to cattail management. This is not a universally popular decision, as 50% of growers are against the change and 33% are in support; and the remaining 17% have no opinion. Moreover, only 50% of the growers will cost-share a cattail management program. While cattail management is designed to disperse roosting blackbirds in the short-term, this technique also reduces habitat for breeding blackbirds in the long-term, a fact not well advertised.

Lilliboe suggests that an avicide, which has been discussed among growers for years, would be more effective at reducing blackbird damage than dispersal techniques. However, the mention of avicides causes concerns among wildlife groups. A USDA official reminds growers the blackbird problem will never be eliminated if the crop and birds coexist. So the key is not control but management of the problem, so that people have the option of growing sunflower. This spokesperson concludes that "Compared to where we were 10 years ago, we're finally making some real progress."

Lilleboe, 1996, Blackbird Project Focuses on Population Reduction

Lilliboe begins this article with the same words that began the 1978 article, "If Old King Cole was a merry old soul, it was probably because he had only four and twenty blackbird to contend with and they were all out of commission." The article recounts the December 1977 meeting at NDSU and chronicles the myriad of bird-dispersal techniques tried, improved upon, and discarded over 19 years. In the late 1970s and early 1980s, growers used Avitrol®; in the 1980s, researchers looked into bird-resistant sunflower, bird sterilants, and taste-aversion; in the early 1990s, the industry saw the development of a herbicide to control cattails. All the while, ADC continued financing 22,000 hours of bird-hazing with airplanes (complete with a back-seat gunner), and farmers used propane boomers, tabasco-treated baits, scarecrow balloons, and fireworks. All of these techniques are bird dispersal techniques that are not designed to reduce populations.

Lilliboe recounts that for the previous three years, USDA scientists have tested the use of DRC-1339-treated rice to kill up to 250,000 blackbirds during spring migration in South Dakota. Researchers are asking: 1) can killing blackbirds translate into reduced damage? and 2) is the avicide killing nontargets? Kleingartner suggests the avicide will not be a "silver bullet," and a combination of cattail control, frightening devices, and rifles must be coupled with the avicide.

A high-level official of the South Dakota Game Fish and Parks Department (SDGFP) is very concerned about the effects of DRC-1339 on pheasants, an economically important game bird in South Dakota. Although USDA scientists have not detected evidence that DRC-1339 is killing pheasants, the SDGFP funds SDSU to conduct laboratory and field trials to answer questions asked about the effects of DRC-1339 on pheasants. Larry Kleingartner, representing the industry's position, expresses frustration that a product with a Section 3 EPA label cannot be used in an operational program. He concludes by saying, "It is time to move on to the next stage in using this tool to hopefully provide some relief to growers experiencing significant dollar losses from blackbirds."

SUMMARY

As articulated through The Sunflower, the NSA insists that bird dispersal techniques are, at best, a temporary solution with questionable results, and at worst, time consuming, expensive, and ineffective. Moreover, the NSA remains steadfast in its desire to have Wildlife Services develop and use an avicide to manage the blackbird population. In stark contrast, wildlife officials consistently write and talk about how to improve and implement bird dispersal techniques, and cast doubt on the efficacy and environmental impacts of population control for reducing sunflower damage. The NSA, to their credit, have always advocated an integrated pest management approach. Undoubtedly, this impasse will be resolved in future years after much public debate.

THE FUTURE

What bird-damage abatement methods will the NSA promote through The Sunflower over the next 20 years? The answer largely depends on what methods NWRC and its cooperators develop and successfully implement in field trials. In the near term (five years), thorough testing of DRC-1339-treated grain baits for managing both spring and late-summer blackbird populations in and near the sunflower-growing region will continue. Additionally, NWRC and the North Dakota-South Dakota Wildlife Services unit have recently agreed to a joint project designed to lower costs and enhance the benefits of using aquatic herbicides to manage cattails (Leitch et al. 1997). In the mid-term (5 to 10 years), biological control of cattails may be touted as an efficacious and environmentally friendly method. We expect that new, less-expensive aquatic herbicides will be developed after the patent expires on Rodeo® early in the next millennium. In the long-term (10 to 20 years), species-specific immuno-contraceptives may be field

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tested for suppressing blackbird populations. Advancements in genetic engineering may result in sophisticated methods of controlling blackbird reproduction or longevity. Finally, a bird dispersal method in the form of a new chemical bird repellent or mechanical scare device may be discovered and warrant field testing.

The authors caution the most environmentally benign damage abatement methods will be subject to much public debate through implementation of the National Environmental Policy Act. Therefore, to maintain credibility it is incumbent on scientists involved in wildlife damage management to provide unbiased data on the efficacy, costs and benefits, and environmental risks of each method.

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THE USE OF NETTING AS A BIRD MANAGEMENT TOOL IN VINEYARDS

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ABSTRACT: Vineyard bird control is an important issue both monetarily and practically. Each season vineyard managers face the real threat of significant crop loss to starlings and finches, as well as an assortment of other birds. The increased popularity of wine as a mainstream consumable has led to a higher crop value in this industry. Because of this, the grape growers can no longer ignore bird damage. Netting, now recognized as the best solution, creates an additional challenge for the grower. To take full advantage of this management tool, a working knowledge of the proper equipment, as well as recognition of the behavioral characteristics and effects of the pest birds, must be combined for maximum effect.

KEY WORDS: netting, starlings, robins, finches, pyrotechnics, NetMaster, vineyard, grape grower, bird damage

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INTRODUCTION

Vineyard bird damage is a growing concern for today's grape grower. The days of "letting the birds have their share" are long gone. Vineyard managers who dedicate their time and effort to higher yield and profits are facing a number of problems caused by bird damage. The most obvious is the completely missing grape. European starlings (*Sturnus vulgaris*), American robins (*Turdus migratorius*), and Cedar waxwings (*Bombycilla cedrorum*) will take whole grapes off the clusters, leaving the grower with a frustrating and expensive visual indicator that he has a problem. House finches (*Carpodacus mexicanus*) and a host of other small birds, generically referred to as "linnets" by most growers, will peck at the clusters of grapes causing damage that leads to insect damage and disease which will destroy the entire cluster. These species make up the bulk of today's grape growers pest species. There are also reported cases of California quail (*Lophortyx californicus*), Mourning dove (*Zenaidura asiatica*), Bullock's orioles (*Icterus bullockii*), Western tanager (*Piranga ludoviciana*), and even Coyote (*Canis latrans*) damaging wine and table grapes. However, these reports are scattered and suspect as these species are frequent visitors to vineyards for various other reasons and are more often than not, guilty by association.

Vineyard bird damage has become an important issue because of the rising value of varietal wine grapes. For example, four years ago Chardonnay wine grapes were worth $888.73 per ton (1993 Final Grape Crush Report, California Department of Food and Agriculture) and now are selling for $1,150.52 per ton (1997 Preliminary Grape Crush Report, California Department of Food and Agriculture). These prices reflect the average price per ton in California of one of several emerging varieties. Some growers have seen increases that are substantially higher than what is noted here. The increase can be traced to two basic sources. Wine has seen an increase in popularity and the supply of wine grapes has fluctuated greatly during the same period of time. The economic laws of supply and demand are now a factor in bird control. The grape grower has sought to capitalize on this business opportunity by increasing the level of sophistication in vineyard management and, subsequently, his yield. The traditional 12/6 approach (12 feet between rows, 6 feet between vines) to vineyard layout is being replaced by row spacing as little as 6 or 8 feet and vertical trellising to allow 4 foot spacing between vines. Frost protection used to be burning tires in the vineyard (this really is a sign of progress). Now, sizable chunks of money are being spent on laser leveling, computerized weather monitoring stations, innovative irrigation options, and vineyard frost protection fans. Canopy management and trellising have almost become an art form. But the unsophisticated constant that remains is bird damage.

Every year growers lose acres of grapes to birds. With an average yield of three to four tons per acre of grapes, these losses quickly add up to thousands of dollars. Whole grapes gone, or clusters of pecked grapes oozing juice and attracting wasps, ants, mildew, and mold, or any combination of these, is enough to send sane, well-educated men and women scrambling for a shotgun at the first sight of a starling.

The traditional approach to bird control has remained basically unchanged for several years. Propane cannons, bird bombs, and whistles have been a well used constant in the vineyard. Noisemaking devices have been and will continue to be a good option for the grower as long as he has the time and resource to employ shooters who can move when and where the birds move to keep the pressure on. In addition, the Federal Migratory Bird Treaty allows one to take starlings. However, few field hands possess the ability to tell the difference, in flight, between starlings and other vineyard pests/visitors.

Visual scare devices such as mylar flagging or flashtape, scare eye balloons, hawk kites and scarecrows are proven to have limited effectiveness. These items work best when combined with noisemaking devices. Hazing of birds is really an attempt to make them feel uncomfortable enough to leave the area. Visual scare devices do make birds nervous, but only for a short period of time, after which hunger overcomes all other urges. The best use of these devices is in combination with a netting program that excludes birds from areas they are most comfortable in. These areas are usually perimeter zones that offer quick escape to available cover.

When these areas are netted, birds are forced to fly farther into the interior than they would otherwise. The presence of visual scare devices and noisemakers located in the "interior" area are much more intimidating than when used as stand alone techniques.

Biosonics and distress calls are a time tested and proven technique for effectively repelling birds from certain areas. However, only recently have they been promoted beyond their effectiveness in an attempted response to the "quick fix" that most growers seek. Here it is proven that throwing money and technology at a problem is not always the answer. While starlings are a vocal enough species to react to a distress call, most other vineyard bird pests are not. In addition, the risk of attracting birds to the area, that may have not paid as much attention otherwise, is very real with distress calls (Conover and Perito 1981). In an effort toward self-preservation, most birds react two distinct ways to a call made when in a predator's grasp. Birds will either leave the area in an all out attempt to escape, or they will flock up and come to investigate the source of the call in an effort to identify the predator in question for future survival. This second option is not what the grape grower has in mind when spending several hundred dollars or more for an electronic calling device.

Trapping is another option that has proven to be effective. Again, it is important to know the laws that apply when trapping, but once a grower has cleared that hurdle, he can count on some results. The most effective use of traps seems to involve the Modified Australian Crow Trap (Praster pers. comm.; Gadd 1996). When used for the entire year, one can actually begin to have an effect on the available breeding population of resident pest species. However, this technique also falls short of many growers' standards and expectations for the elusive "quick fix." While scoring high in the "visually rewarding" department, most trapping programs are not feasible for growers either because of public relations or the lack of available qualified personnel to implement the program.

The difference between success and failure with these techniques often times may not even depend on the individual grower's tenacity and effort. Instead, fluctuating population levels of migratory species often determine the level of damage. The availability of alternate food sources also plays a large role in the pressure birds will place on a grower. Just as the weather will influence a grape grower's cultural management practices, the success or failure of species', such as starlings or finches, breeding cycles will also have an impact on management practices in the vineyard.

NETTING

With all the other available options, netting has only recently been considered a viable tool for vineyard protection. The obvious objections come immediately to mind—it must be more expensive, more labor intensive and, in general, more hassle than it is worth to use in the first place. The use of netting has always assumed two basics: 1) you cannot use it if you have very much to cover; and 2) you cannot make it last long enough to pay for itself. Those who have considered it beyond this point realize that the option of physical exclusion, while attractive, must be too good to be true. The reality is that netting is the best option available to the grower. In addition to offering total protection against bird damage, it is portable, easy to obtain, requires very little training or a skilled specialist to make it successful, and represents the only "install and forget" product that will solve a grower's bird problems.

It is now apparent that the grower with 2 acres, as well as the grower with 120 acres, can profit from using netting. Today we are seeing the "niche" grower who offers a specialized varietal wine grape that may cost a winery in excess of $2,000 per ton. A 10-acre parcel of this crop can be entirely covered at a cost of roughly $350 per acre. In addition to low-cost protection, growers have two types of netting available—reusable netting which has a five to seven year life expectancy, and disposable netting which may be used for one season and then thrown away. Reusable netting affords the grower the option of paying a higher cost initially to be rewarded by lower amortized costs over the course of the following five to seven years. This method allows some growers to see costs dip below $100 per acre.

Netting is commonly used across the nation. California growers have learned to net the entire vineyard, when practical, and to combine netting and scare devices when it is preferable to net only those areas that receive the most pressure. East Coast growers net the entire vineyard (Fuller-Perrine and Tobin 1993), with some choosing to support the net overhead allowing access for equipment and workers under a net canopy. Growers in Canada have used netting that is five to six feet wide and installed it vertically (Murray unpubl. data 1997). This technique takes advantage of the fact that most Canadian growers use a vertical trellis system to maximize exposure to sunlight in a shorter growing season. By vertically netting down both sides, these growers cover the fruiting zone of the vine to protect the grapes.

A grower's general management practices including irrigation, choice of cover crop, disease control and insect control are affected by the use of netting. Most have felt that netting would get in the way of these other vital management practices. Planning to use netting has dispelled most worries. However, planning for netting and bird control, in general, has only recently become part of a grower's practice.

The "good ol' days" of grape growing allowed bird control to pass as an issue when large migratory flocks of starlings were an every other year occurrence. Present day California supports an impressive and imposing resident population of starlings that guarantee every year may be a bad bird year. Netting is most effective when draped over the vines creating a protective canopy. This is important especially to growers with starling problems, as starlings land in the canopy and work their way down to the fruit. Canopy coverage does not need to encase the vine, but rather exclude entry from the top and sides at the fruiting zone. Growers with robin and finch damage, on the other hand, must make sure that the netting fully encases the vine, as these two common pests feed from ground level up.

For row application, netting can be applied two basic ways. The most traditional has been to unroll the net the length of the row and then lift it in sections, placing it on top of the vines. It is then spread down both sides of the canopy and either allowed to touch the ground or it is fastened underneath. The second and more developed method of net installation is the use of over the row application equipment. This equipment requires the use of a tractor and is considerably faster and less labor intensive than the more traditional approach. In addition, it makes care of the netting easier as the process is somewhat more developed.

APPLICATION AND REMOVAL OF NETTING

Growers have built several net application and removal systems over the years. Most devices relied on one of two principals—either make the net small enough to handle easily, or build the equipment big enough to handle almost anything. Conwed Plastics based in Minneapolis, Minnesota, manufactures extruded polypropylene netting in bulk rolls 14 and 17 feet in width and 5,000 feet in length. The net weighs between 230 to 280 pounds in this bulk form. In addition, Conwed also manufactures disposable netting, available in 17 feet by 20,000 feet rolls at a weight of 690 pounds. These physical characteristics have challenged many a vineyard equipment maintenance man over the years.

In 1998, the first commercial bulk roll applicator becomes available. The "NetMaster" handles the same rolls but breaks from the convention of "over the row" suspension of the bulk rolls. Instead the netting lies on a trailer, parallel to the row and direction of travel and, most notably, about 18 inches above ground level. The net is then hydraulically paid off the roll and distributed over the row by a bar and sweep assembly. This process is safer, easier to use, and faster than the conventional over the row bulk roll applicators. Using this method allows the grower to cover 4 to 5 acres per hour with netting.

The next challenge the grower faces with netting is retrieval of the product with the intent of easy storage and reuse the following year. Previously, it was hydraulically or manually wound back onto a homemade 14 or 17 foot core. The effort to reproduce the manufacturer's tensioning of the netting would be made to maximize the amount of net stored per core. Needless to say, this process lends itself to net damage, sore arms, and a colorful vocabulary.

The NetMaster is comprised of three basic pieces of equipment—the bulk roll applicator, the net retriever, and the spool applicator. The net retriever is the key piece of equipment. Using the same sweep and distributor bar the bulk roll applicator uses, the retriever lifts the net off the vines and level winds it onto 24-inch spools. This method allows roughly 2,000 feet of netting to be wound onto a spool. The grower then removes the spool, marks which rows it was applied to, and stores it for reapplication the following year. This method of retrieval allows the grower to pick up 4 to 5 acres of netting per hour. In addition, spools with an overall length of 24 inches and a diameter of 24 inches are much easier to stack and store than a homemade "net on a core" assembly that is 14 or 17 feet long. The spool applicator allows the grower to hang the filled spools of net, weighing about 70 pounds, directly over the rows the following year for quick application.

The benefit to the grower in using a system like this is demonstrated in the following ways. Mechanization of the netting process allows the grower to realize the savings sought by using netting. It makes the application process faster and safer. It enables vineyard managers to allocate their labor resources to other tasks. It adds longevity to the net itself. Finally, it completely addresses the problem of vineyard bird damage. The retrieval of netting prior to harvest and reapplication the next year is the key to making netting a viable solution, practically and financially, for today's grape grower.

CONCLUSION

It is an overstatement to say that one piece of equipment or even one approach makes the battle of vineyard bird control an easy one. Years of research, effort, ingenuity, and trial and error have demonstrated that there is no easy solution. The use of netting as a bird management tool in vineyards can be viewed as literally as it is written—a management tool. Netting is the most effective tool, but the other techniques discussed here all have their merit. The grower that comes closest to winning the fight and making the most money with his crop is also the grower who understands that bird control, like so many other vital management practices, cannot be ignored. Vineyard bird control requires investment of time, money, and effort. These investments show the grower the basics of what is causing the damage and allow him to make the best decision about how to minimize that damage.

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POPULATION TRENDS AND ECOLOGICAL ATTRIBUTES OF INTRODUCED PARROTS, DOVES AND FINCHES IN CALIFORNIA

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ABSTRACT: At least 10 species of parrots (Family Psittacidae), along with the Eurasian Collared-Dove (Columbidae: *Streptopelia decaocto*), Orange [Northern Red] Bishop (Ploceidae: *Euplectes franciscanus*), and Nutmeg Mannikin ["Spice Finch" or "Spotted Munia"] (Estrildidae: *Lonchura punctulata*), have recently established significant viable and generally increasing populations in California. Populations of all of these taxa are concentrated in highly modified urban and suburban habitats (parrots, doves) or in flood control basins and river channels with abundant rank annual growth (bishop, mannikin). With various collaborators, the author has monitored these taxa in southern California through the 1990s. Because of the potential for deleterious ecological interactions with native bird species and for damage to certain commercial crops, monitoring of these species and other potentially established exotic bird species must be ongoing. Here the author reports his present knowledge of population sizes and trends, geographical distribution, habitat relationships, and foraging and breeding ecology of these introduced species and suggest schemes for continued monitoring.

KEY WORDS: birds, bishop, California, conure, dove, mannikin, munia, parakeet, parrot, vertebrate pests

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INTRODUCTION

In discussing exotic bird species in southern California, Hardy (1964) summarized the Los Angeles region as "... little more than a gigantic aviary wherein agriculture is heavily practiced and where individuals of any tropical or temperate bird species might escape to persist for a time and carry out its breeding cycle." This statement has proven prophetic, for, in the nearly three decades since Hardy's comment, species diversity and population sizes of "exotic" bird species have grown considerably. Birds have long been introduced into California for hunting, aesthetics, or by accident (Grinnell and Miller 1944; Long 1981; Johnson and Garrett 1994); some bird species have reached California by spreading from introductions elsewhere into North America. Concerns about the ecological impacts of non-native bird species are not new, but are increasing (Temple 1992). Additional concerns center around the economic impact of non-native birds on agriculture.

This review excludes introduced game species (most recently reviewed by Small 1994). Similarly, ornamental waterfowl and pheasants are not considered here, although the Mute Swan (*Cygnus olor*), Egyptian Goose (*Alopochen aegyptiacus*), and Common Peafowl (*Pavo cristatus*), among other species, should be closely monitored in California. The status, distribution and natural history of four "standard," long-established non-game species in California, Rock Dove (*Columba livia*), Spotted Dove (*Streptopelia chinensis*), European Starling (*Sturnus vulgaris*), and House Sparrow (*Passer domesticus*) are relatively well-known (Johnston 1992; Lowther and Cink 1992; Cabe 1993; Johnston and Garrett 1994; Garrett and Walker, in prep.) and need not be discussed further here, although potential interactions between the Spotted Dove and the naturalizing Eurasian Collared-Dove (*Streptopelia decaocto*) are of considerable interest.

Additionally, the author does not treat several localized introductions. Some of these have been intentional (e.g., Northern Cardinal, *Cardinalis cardinalis*). Other, accidental, introductions and have caused concern to agricultural agencies but have now largely been "controlled;" these include the Oriental (Japanese) White-eye (*Zosterops palpebrosa*) and Red-whiskered Bulbul (*Pycnonotus jocosus*).

In this paper the author concentrates on a group of species which have recently thrived in extensively modified habitats of urban and suburban areas and, in some cases, near important agricultural regions. All of these species are of potential concern as agricultural pests, and could negatively impact native bird species, either directly or through diffuse (community) impacts. The main goal is to summarize the current status and ecological attributes of these species in hopes that this information will be of value to those charged with managing California's native biodiversity and agriculture.

METHODS

Information was obtained through literature review, ongoing field work, and a citizen science project to monitor parrots; the last was recently summarized by Garrett (1997). Some information was supplied by W. S. Smithson from his ongoing research on bishops and mannikins. The field identification of many of these taxa is not covered in standard North American field guides; useful identification papers included Craig (1992) for *Euplectes*, Restall (1997) for *Lonchura*, and Smith (1987) for *Streptopelia*.

RESULTS

The species treated in the following accounts appear to be naturalized within California. In most cases their populations have reached levels in the hundreds or thousands, they have spread beyond a single confined geographical area, they have maintained stable or increasing populations, and reproduction in the wild appears to be the main source of population recruitment. The inclusion of some species may be marginal, but even these species are of potential concern.

Rose-ringed Parakeet (*Psittacula krameri*) - "Ring-necked Parakeet"

Native Range and Habitat: Central Africa (Senegal east to Uganda); Indian Sub-continent to Burma; naturalized in Britain (Morgan 1993) and elsewhere. Lightly wooded areas, cultivated areas, plantations, savannas, deciduous woods, semidesert scrub (Forshaw 1989).
Distribution in California: Mainly Los Angeles County, especially coast from Malibu to Westchester and Temple City area of San Gabriel Valley (Garrett 1997); at least formerly in Highland Park, Los Angeles County, and San Bernardino vicinity (Hardy 1964, 1973). California birds of unknown subspecies, but almost certainly from the Indian subcontinent and likely *manillensis*.
Habitat in California: Urban and suburban areas, especially in lower portions of coastal canyons dominated by sycamores, *Platanus racemosa* (Garrett 1997).
Elevation Range: 0 to 2000 m in Old World range (Forshaw 1989); 0 to 200 m in southern California (Garrett 1997).
Primary Diet: Seeds, berries, fruits, blossoms, nectar (Forshaw 1989); in southern California 14 diet items noted by Garrett et al. (1997), including sycamore and plane tree (*Platanus*) seeds and seed at feeders. Considered "serious pests" in orchards, coffee plantations, and croplands in native range (Forshaw 1989). Pest potential in California examined by Shelgren et al. (1975).
Foraging Substrate and Techniques: Trees, shrubs, occasionally ground; picks, chews with bill.
Breeding Season: Few data for California; peak appears to be in April (Mabb 1997b).
Nest Site and Materials: Cavity in tree (natural or woodpecker-drilled; niches under roofs, holes in walls, even earth mounds (Forshaw 1989). Nests in California have been in palms (Garrett, pers. obs.) and silver maples (Mabb 1997b); known nest heights about 10 m.
Mating System: Monogamous pairs.
Clutch Size: 3 to 5 (Forshaw 1989); 8 eggs in one nest in California (Hardy 1964).
Broods/Year: No data for California; probably one.
Incubation Period: 22 days (Forshaw 1989).
Fledging Period: 7 weeks (Forshaw 1989).
Age at First Breeding: Usually 3 years (Forshaw 1989).
California Population Size and Trends: About 64 estimated in greater Los Angeles area as of 1997 (Garrett 1997). Stable or possibly decreasing. Present and presumably nesting in Eagle Rock, Los Angeles County, 1956 to 1963 (Hardy 1964), but largely gone from there by the early 1970s. Population in Zuma Canyon, Malibu, Los Angeles County, appears to have decreased since late 1970s and early 1980s (Garrett 1997, pers. obs.).

Blue-crowned Parakeet (*Aratinga acuticaudata*)

Native Range and Habitat: South America; nominate subspecies, which appears to be the one established in California, occurs in Brazil, E. Bolivia, Paraguay, and N. Argentina (Forshaw 1989); Found in dry woodlands, shrublands, gallery (riparian) woodland (Forshaw 1989).
Distribution in California: San Fernando Valley (especially Northridge), coastal Los Angeles County (vicinity of Redondo Beach), and San Diego. Sightings also for Simi Valley, Ventura County.
Habitat in California: Residential areas with exotic plantings.
Elevation Range: In South America, found from lowlands up to 1800 m, and regularly to 2600 m (Stotz et al. 1996); in California, 0 to 250 m (Garrett 1997).
Primary Diet: Seeds, fruits, berries, nuts; known to damage sorghum crops in Paraguay (Forshaw 1989). In southern California, pepper (*Schinus*) and five other food items from exotic plants (plus seed at feeders) listed by Garrett et al. (1997).
Foraging Substrate and Techniques: Bushes, trees, sometimes ground (Forshaw 1989); uses bill to obtain food.
Breeding Season: No data for California; eggs recorded in Argentina in December (Forshaw 1989).
Nest Site and Materials: Tree cavity; no data for California.
Mating System: Presumably monogamous pairs.
Clutch Size: 2 to 3 (Forshaw 1989).
Broods/Year: No data.
Incubation Period: 23 days in captivity (Forshaw 1989).
Fledging Period: 50 days in captivity (Forshaw 1989).
Age at First Breeding: No data.
California Population Size and Trends: In greater Los Angeles area probably only about 50 individuals, but apparently increasing (Garrett 1997). Population establishment recent; species not noted by Hardy (1973).

Mitred Parakeet (*Aratinga mitrata*) - "Mitred Conure"

Native Range and Habitat: Central and southern Peru (east of Andes) to eastern Bolivia, northwestern Argentina; California birds appear to be from the nominate subspecies. Woodlands, small forest patches, arid montane slopes and valleys (Forshaw 1989); steep hills and rock faces, legume-dominated deciduous and cloud forest (Fjeldså and Krabbe (1990).
Distribution in California: Naturalized in coastal areas from Malibu to Long Beach and coastal northwestern Orange County, and also in the Los Angeles basin and San Gabriel Valley; small numbers (naturalized?) from San Francisco to south San Francisco Bay region, and sightings also in San Diego and Sacramento areas (Garrett 1997).
Habitat in California: Urban parks, suburban residential areas (Garrett 1997).
Elevation Range: In South America, 1000 to 2500 m (Stotz et al. 1996); in California generally 0 to 300 m (Garrett 1997).
Primary Diet: Seeds, fruits, flowers (Forshaw 1989); in southern California 32 items recorded by Garrett et al. (1997) and Collins and Kares (1997), especially sycamores (*Platanus* spp.), *Eucalyptus sideroxylon*, *Ficus* spp., *Magnolia grandiflora*, *Myoporum laetum*.
Foraging Substrate and Techniques: Trees, shrubs, occasionally seed feeders; uses bill to obtain food, bill and feet to manipulate food.
Breeding Season: In southern California copulation noted in March, and presumed fledged young in July and

August (Collins and Kares 1997); in native range eggs noted in December (Fjeldså and Krabbe 1990).
Nest Site and Materials: In South America, nests in cliffs or tree hollows (Fjeldså and Krabbe); one nest noted in tree cavity at 10 m (Forshaw 1989). Few data for California, but appears to use building niches and drainpipe holes as well as tree cavities (Garrett, pers. obs.).
Mating System: Presumably monogamous pairs.
Clutch Size: 2 eggs (Forshaw 1989).
Broods/Year, Incubation Period, Fledging Period, Age at First Breeding: No data.
California Population Size and Trends: Greater Los Angeles area population estimated at 680 by Garrett (1997); small numbers at scattered localities elsewhere in the state. Unknown prior to late 1970s or early 1980s (Garrett 1997); not mentioned in review by Hardy (1973). Substantial increases since the 1980s, with numbers apparently continuing to build.

<u>Red-masked Parakeet (*Aratinga erythrogenys*) - "Cherry-headed Conure"</u>
Native Range and Habitat: Western Ecuador and northwestern Peru; arid coastal lowlands, deciduous forest, dry scrub, open desert and towns (Forshaw 1989).
Distribution in California: San Gabriel Valley and Redondo Beach areas of Los Angeles County; San Francisco and possibly San Diego areas (Garrett 1997); scattered observations elsewhere.
Habitat in California: Residential urban and suburban areas; usually in the same areas as Mitred Parakeets (Garrett 1997).
Elevation Range: In Tumbesian South America found from lowlands to 800 m (Stotz et al. 1996); in California mainly 0 to 300 m.
Primary Diet: Seeds, fruits, nectar; in southern California Garrett et al. (1997) noted six food items, including *Eucalyptus* flowers, *Myoporum laetum* berries, sycamore seeds.
Foraging Substrate and Techniques: As in Mitred Parakeet.
Breeding Season: No data.
Nest Site and Materials: No data; presumably in tree cavities.
Mating System: Presumably monogamous pairs.
Clutch Size: Clutch of 3 reported by Forshaw (1989).
Broods/Year: No data.
Incubation Period: 23 days (Forshaw 1989).
Fledging Period: 50 days (Forshaw 1989).
Age at First Breeding: No data.
California Population Size and Trends: Greater Los Angeles area population estimated at about 70 by Garrett (1997); up to several dozen may occur in the San Francisco Bay area (M. Bittner, pers. comm.). Populations apparently increasing; not reported by Hardy (1973) and apparently first established in the 1980s or early 1990s.

<u>Black-hooded Parakeet (*Nandayus nenday*) - "Nanday Conure"</u>
Native Range and Habitat: Southeastern Bolivia, southwestern Brazil, Paraguay, northern Argentina (Forshaw 1989); open country, pantanal (seasonally flooded grasslands), savannas, croplands, palm groves (Forshaw 1989).
Distribution in California: Coastal Los Angeles and Orange counties, especially from Brentwood and Pacific Palisades to Malibu; a few in the San Gabriel Valley (Garrett 1997). Also noted in Sacramento (Garrett 1997) and formerly in Loma Linda area of San Bernardino County (Hardy 1973; Fisk and Crabtree 1974).
Habitat in California: Suburban residential areas, often in or near coastal canyon mouths (Garrett 1997).
Elevation Range: Lowlands to 800+ m in South America; in California, mainly coastal, 0 to 100 m.
Primary Diet: Seeds, fruits, nuts, berries (Forshaw 1989); in southern California, noted feeding on chinaberries (*Melia azederach*; Fisk and Crabtree 1974) and seven other items including sycamore fruits and sunflowers (Garrett et al. 1997).
Foraging Substrate and Techniques: Trees, shrubs, ground.
Breeding Season: The few data in California suggest most breeding is in spring, summer (Fisk and Crabtree 1974, KLG pers. obs.). Nesting recorded in late November in Brazil (Forshaw 1989).
Nest Site and Materials: Hollows in tops of fenceposts and presumably also trees (Forshaw 1989); in California nests in hollows in sycamores (*Platanus racemosa*) and other trees (Garrett 1997). No nest lining employed (Forshaw 1989).
Mating System: Presumably monogamous; an observation reported in Forshaw (1989) suggests that more than two adults may be present at nest site.
Clutch Size: 3 to 4 (Forshaw 1989).
Broods/Year: No data.
Incubation Period: 21 to 23 days in captivity (Forshaw 1989).
Fledging Period: About 56 days (Forshaw 1989).
Age at First Breeding: No data.
California Population Size and Trends: Garrett (1997) estimated at least 180 birds in the greater Los Angeles area. Small populations noted by Fisk and Crabtree (1974) may not be extant, but numbers in coastal Los Angeles and Orange counties may be increasing.

<u>White-winged Parakeet (*B. versicolurus*) - "Canary-winged Parakeet" in part, "Bee-bee Parakeet"</u>
Native Range and Habitat: Northern Amazonia from southeastern Colombia and northeastern Peru east to the Amazon River mouth (Forshaw 1989). Humid lowland forest and edge, second growth (Brightsmith in press). Naturalized in Florida (Smith and Smith 1993; Brightsmith in press).
Distribution in California: Limited numbers in San Francisco (Arrowood 1981) and south coastal Los Angeles County (Redondo Beach and Palos Verdes Peninsula; Garrett 1997).
Habitat in California: Coastal residential and suburban area with exotic flora, especially palms (Garrett 1997).
Elevation Range: In South America, 0 to 1,000 m (Stotz et al. 1996). In California, mainly around sea level (to 50 m).
Primary Diet: Seeds, fruit, blossoms (Brightsmith in press). In San Francisco area Arrowood (1981) lists 11

food items, including palm fruits (dates), leaf buds, flowers, figs, apples.
Foraging Substrate and Techniques: Arboreal; usually high in trees (Forshaw 1989; Brightsmith in press).
Breeding Season: In Florida fledglings noted February to July (Brightsmith in press); in San Francisco nesting mainly March to July (Arrowood 1981). Nestlings have been collected in Los Angeles County, California in June (Garrett 1997).
Nest Site and Materials: Tree cavities, or among palm fronds (Brightsmith in press); nest heights in Florida 2 to 12+ m (Brightsmith in press). Especially apt to nest in date palms (*Phoenix*) in California (Arrowood 1981).
Mating System: Monogamous, with long-term pair bonds (Brightsmith in press).
Clutch Size: 5 or more eggs (Forshaw 1989; Brightsmith in press).
Broods/Year: 1 (Brightsmith in press).
Incubation Period: 25 to 26 days (Brightsmith in press).
Fledging Period: 5 to 6 weeks (Forshaw 1989).
Age at First Breeding: 2 to 3 years in captive birds (Forshaw 1989).
California Population Size and Trends: Greater Los Angeles area populations only about 20 birds (Garrett 1997); probably similar numbers in San Francisco area. Has apparently decreased since 1960s and 1970s in Los Angeles area, perhaps because of interactions with Yellow-chevroned Parakeets (Garrett 1997).

<u>Yellow-chevroned Parakeet (*Brotogeris chiriri*) - "Canary-winged Parakeet" in part, "Bee-bee Parakeet")</u>
Native Range and Habitat: Mainly south of the Amazon region, from Bolivia and eastern and southern Brazil to Paraguay and northern Argentina (Forshaw 1989). Open woodlands, savannas, subtropical forests, towns (Brightsmith in press). Naturalized in southern Florida (Smith and Smith 1973).
Distribution in California: Los Angeles basin south to Palos Verdes Peninsula and east to southwestern San Gabriel Valley (Garrett 1997); possibly established (along with White-winged Parakeets) in San Francisco.
Habitat in California: Urban and suburban areas with exotic flora, especially silk-floss trees (*Chorisia speciosa*), palms, and eucalyptus (Garrett 1997).
Elevation Range: In South America from near sea level to 1,200 m and sometimes 1,560 m (Stotz et al. 1996; Forshaw 1989); in California from sea level to about 300 m (Garrett 1997).
Primary Diet: Seeds, fruit, blossoms (Brightsmith in press). In southern California (Garrett et al. 1997) noted taking 11 different items (including commercial bird seed at feeders), but concentrating on seeds of silk-floss tree and blossoms of red ironbark (*Eucalyptus sideroxylon*).
Foraging Substrate and Techniques: Canopy and subcanopy (Brightsmith in press).
Breeding Season: In Florida similar to White-winged (Brightsmith in press).
Nest Site and Materials: Cavities in tree trunks (especially palms) or limbs; holes excavated in arboreal termite nests (Forshaw 1989); nests in California have mainly been in palms.
Mating System: Monogamous (Forshaw 1989).
Clutch Size: 5 to 6 (Forshaw 1989).
Broods/Year: No data.
Incubation Period: About 26 days in captivity (Forshaw 1989).
Fledging Period: About 56 days in captivity (Forshaw 1989).
Age at First Breeding: No data.
California Population Size and Trends: Greater Los Angeles area population estimated at at least 380 birds (Garrett 1997). Not established in California until after the early 1970s, with great increases since then taking place mainly in the late 1980s and 1990s (Garrett 1997).

<u>Red-crowned Parrot (*Amazona viridigenalis*) - "Green-cheeked Amazon"</u>
Native Range and Habitat: Eastern Mexico (Tamaulipas and Nuevo Leon to northern Veracruz); semi-deciduous tropical forests, scrub, older cities (Enkerlin-Hoeflich 1997). Naturalized in southernmost Texas and Florida.
Distribution in California: Urban coastal slope of southern California, from Los Angeles County (especially San Gabriel Valley) to Orange County; also locally in San Diego area (Garrett 1997); small numbers have been noted on the Monterey Peninsula (Roberson and Tenney 1992).
Habitat in California: Older urban and suburban areas, especially with a combination of exotic trees and shrubs, small orchards, and native live oaks (*Quercus agrifolia*) (Froke 1981; Hall 1988; Garrett 1997).
Elevation Range: In Mexico from sea level to 1,200 m (Stotz et al. 1996); in California mainly 0 to 400 m (Garrett 1997).
Primary Diet: Seeds, fruit, buds, flowers (Enkerlin-Hoeflich 1997); in southern California Garrett et al. (1997) noted 24 diet items, including sycamore fruits, *Ficus*, sweetgum (*Liquidambar*) fruits, acorns from *Quercus* spp., pecans, walnuts, and *Eucalyptus* blossoms. Froke (1981) listed additional food items.
Foraging Substrate and Techniques: Tree crowns, shrubs. Manipulates food with bill and feet.
Breeding Season: In San Gabriel Valley of southern California dependent, fledged young mainly noted from July to October, with extremes from April to December (Mabb 1997b).
Nest Site and Materials: Existing cavities (from woodpeckers or natural decay) in trees (Enkerlin-Hoeflich 1997). In San Gabriel Valley silver maples (*Acer saccharinum*) especially important, but also uses utility poles (Mabb 1997b); may be somewhat colonial in nest site choice. Froke (1981) reported nests in blue gums (*Eucalyptus*) in the San Gabriel Valley at heights of 14 m and 18 m.
Mating System: Probably monogamous pairs (Enkerlin-Hoeflich 1997).
Clutch Size: Mean in northeastern Mexico 3.4 (n=53; Enkerlin-Hoeflich 1997). No data for California.
Broods/Year: 1 in native range (Enkerlin-Hoeflich 1997); no data for California.
Incubation Period: 27 days (n=36; Enkerlin-Hoeflich 1997).
Fledging Period: 53 days (n=17; Enkerlin-Hoeflich 1997).

Age at First Breeding: Unknown in native range (Enkerlin-Hoeflich 1997), but perhaps 3 years (Forshaw 1989).
California Population Size and Trends: Greater Los Angeles area population conservatively estimated at 1,080 by Garrett (1997); strong increases since the 1960s and 1970s, when reported as "very rare" by Hardy (1973) and only about 50 birds estimated for the San Gabriel Valley by Froke (1981). Large numbers of juveniles noted annually in recent years (Mabb 1997b) indicating high nesting success. Size of roosting flocks in the San Gabriel Valley continues to increase (Mabb 1997a and pers. comm.).

Lilac-crowned Parrot (*Amazona finschi*)
Native Range and Habitat: Western Mexico from Sonora and Chihuahua south to Oaxaca (Howell and Webb 1995); wooded foothills, coastal hills and mountains; deciduous forest, thorn scrub, oaks (Forshaw 1989; Howell and Webb 1995).
Distribution in California: Similar to Red-crowned Parrot but considerably less numerous; mainly in the San Gabriel Valley, Los Angeles County.
Habitat in California: Residential and suburban areas; sometimes in native oaks, and has nested (at least once) in native coniferous forest in the San Gabriel Mountains (Garrett 1997).
Elevation Range: In Mexico from sea level to 2,200 m; in southern California mainly 0 to 400 m, but one probable nesting pair was noted at 1,600 m (Garrett 1997).
Primary Diet: Fruits (especially figs), nuts, berries, buds, blossoms (Forshaw 1989). In southern California noted taking 21 items, including sycamore and sweetgum (*Liquidambar*) fruits, figs, pecans, apricots, and *Eucalyptus* blossoms (Garrett et al. 1997); Froke (1981) lists some additional food items.
Foraging Substrate and Techniques: Usually high in trees, tall shrubs (Forshaw 1989).
Breeding Season: In Mexico at least from February to July (Forshaw 1989). In southern California nestlings noted in May and June (Froke 1981; Mabb 1997b); dependent fledged young peak from July to September (Mabb 1997b).
Nest Site and Materials: Cavities (natural or drilled by woodpeckers) in trees (Forshaw 1989); nests in southern California noted in utility pole at about 8 m (Mabb 1997b) and in cavity in blue gum at 20 m (Froke 1981).
Mating System: Monogamous pairs (Forshaw 1989).
Clutch Size: 2 (Forshaw 1989).
Broods/Year: No data; probably only one.
Incubation Period: 28 to 29 days in captivity (Forshaw 1989).
Fledging Period: About 60 days in captivity (Forshaw 1989).
Age at First Breeding: Probably 3 years in most *Amazona* (Forshaw 1989).
California Population Size and Trends: Greater Los Angeles area population conservatively estimated at about 100 birds (Garrett 1997); an unknown additional number in the San Diego area. Numbers may be considerably higher; difficulty of distinguishing Red-crowned and Lilac-crowned parrots in the field (as well as the confounding factor of potential hybrid young) makes confident population estimates difficult. Hardy (1973) did not record this species in the late 1960s, and Froke (19981) estimated about 22 for the San Gabriel Valley in the late 1970s. Populations have clearly increased since those studies.

Yellow-headed Parrot (*Amazona oratrix*) - "Yellow-headed Amazon"
Native Range and Habitat: Mexico, from Colima in west and Nuevo Leon and Tamaulipas in east, south to Oaxaca and Yucatan; closely related species occur south into South America (Forshaw 1989); riverine woodland, wooded areas with fields, deciduous forest and thorn forest (Forshaw 1989).
Distribution in California: Mainly Los Angeles basin, San Gabriel Valley, and urban Orange County (Garrett 1997).
Habitat in California: Residential, suburban areas.
Elevation Range: In Mexico from 0 to 900 m (Howell and Webb 1995; Stotz et al. 1996); in southern California mainly 0 to 300 m (Garrett 1997).
Primary Diet: Fruits, seeds, nuts, berries, blossoms, leaf buds (Forshaw 1989); in southern California noted feeding on walnuts, sweetgum, olives, camphor, Eucalyptus blossoms, junipers, sycamores (Froke 1981; Garrett et al. 1997).
Foraging Substrate and Techniques: Trees, shrubs.
Breeding Season: No data.
Nest Site and Materials: Hollows (which may be self-excavated) in live trees (Forshaw 1989); in California, also among palm fronds (Froke 1981).
Mating System: Monogamous pairs (Forshaw 1989).
Clutch Size: 2 to 4, usually 3 (Forshaw 1989).
Broods/Year: No data, but probably only 1.
Incubation Period: About 29 days in captivity (Forshaw 1989).
Fledging Period: About 60 days in captivity (Forshaw 1989).
Age at First Breeding: Probably about 3 to 4 years, as in other large parrots (Forshaw 1989).
California Population Size and Trends: Garrett (1997) estimated about 60 birds in the greater Los Angeles area. Has declined since the 1960s to 1970s, when considered "fairly common" by Hardy (1973); now largely absent from the West Los Angeles area, where not uncommon in the 1970s (Garrett 1997).

Eurasian Collared-Dove (*Streptopelia decaocto*)
Native Range and Habitat: India, western Asia, China west to Balkan region; has rapidly spread through Europe during the 20th century (Cramp 1985). Introduced in eastern Asia and the Bahamas, and has spread from the Bahamas to Florida and much of the southeastern United States; establishment in the Americas detailed by Smith (1987). Semi-open, cultivated areas, dry deciduous regions, suburbs, farmyards, orchards; generally avoids open areas, urban centers (Cramp 1985); a human commensal in much of its range.
Distribution in California: A small population of unknown origin was established in Ventura, Ventura County, by 1992 (Small 1994), and has since spread (though not contiguously) to coastal Santa Barbara and San Luis

Obispo counties. Recent sighting (March 1998) for the Antelope Valley near Lancaster, Los Angeles County (Garrett, pers. obs.).
Habitat in California: Coastal towns, suburban areas.
Elevation Range: Primarily lowlands; in California, mainly 0 to 100 m (although the recent Antelope Valley sighting is for 750 m).
Primary Diet: Cereal grains; also seeds, fruits of herbs and grasses, rarely insects (Cramp 1985); often feeds on spilled grain (Goodwin 1983).
Foraging Substrate and Techniques: Ground; rarely in bushes, trees (Cramp 1985).
Breeding Season: Prolonged; in northwestern Europe mainly from March to October (Goodwin 1983; Cramp 1985); no data for California.
Nest Site and Materials: Tree, bush, tall hedge, or building ledge; mean height of 6.77 m (Cramp 1985); nest is a flimsy platform of stems, twigs (Cramp 1985). No data for California.
Mating System: Monogamous; pairs are persistent, year-round (Cramp 1985).
Clutch Size: 2 (97% of all clutches; Cramp 1985).
Broods/Year: 3 to 6 per year (Cramp 1985).
Incubation Period: 14 to 16 days (Cramp 1985).
Fledging Period: 15 to 19 days (Cramp 1985).
Age at First Breeding: 1 year or less (Cramp 1985).
Longevity: Oldest known in wild was 13 years, 8 months (Cramp 1985).
California Population Size and Trends: Established in the Ventura Marina area, Ventura County by the early 1990s. Now numbers from several dozen to the low hundreds in that area (Garrett, pers. obs.). Small local populations became established in Santa Barbara [where not previously present (Lehman 1994)], Morro Bay, Cambria, and perhaps elsewhere by 1998. The explosive population growth and range expansion of this species in Europe (Cramp 1985; van den Bosch et al. 1992) and southeastern United States (Smith 1987; Stevenson and Anderson 1994) suggests that California populations will also rapidly expand.

Nutmeg Mannikin (*Lonchura punctulata*) - "Spice Finch," "Scaly-breasted Munia," "Spotted Munia," "Ricebird"
Native Range and Habitat: India, southeast Asia, Philippine Islands, Indonesia (Restall 1997). Open and semi-open country with bushes, trees, scrub; secondary forest, grassy clearings, cultivated areas, parkland, gardens, urban areas (Restall 1997). Widely introduced in eastern Asia, Australia, Hawaiian Islands, Indian Ocean islands, West Indies, etc. (Long 1981; Restall 1997).
Distribution in California: Lowland river systems and surrounding parks and residential areas from San Fernando and San Gabriel Valleys, Los Angeles County, south to coastal Orange County; small scattered populations from Ventura to San Diego, and perhaps in the south San Francisco Bay area. (Garrett, pers. obs.; Smithson 1997).
Habitat in California: Urban parks with low, weedy growth, flood control basins, river bottoms, gardens, residential areas with seed feeders (Garrett, pers. obs.; Smithson 1997).
Elevation Range: Sea level to 3,000 m in native range (Restall 1997); in California noted mainly from sea level to 800 m (Garrett, pers. obs.; Smithson 1997).
Primary Diet: Grass and weed seeds, waste grain, crumbs, and cultivated rice (Restall 1997), and cultivated sorghum (Goodwin 1982). In California, feeds on seeds of grasses such as *Echinochloa*, *Paspalum*, *Bromus*, *Avena*, and *Cortaderia* (Smithson 1997); also on commercial bird seed provided at feeders.
Foraging Substrate and Techniques: Grass and weed stalks, ground, feeders.
Breeding Season: Nests year round in native range (Restall 1997), especially during and after the rainy (monsoon) season (Goodwin 1982). Nesting in California has been noted from February to November (Smithson 1997).
Nest Site and Materials: The nest is placed in a tree, tall bush, building niche, or thatched roof (Restall 1997). In California most nests have been in exotic pines, but also in other exotics, willows (Smithson 1997); mean height of 26 nests in southern California was 5.6 m (Smithson 1997). The nest is made of grasses and straw, and may be up to "watermelon" size (Restall 1997); it is globular, not woven, and has an entrance hole at one side.
Mating System: Probably monogamous; may be somewhat colonial (Restall 1997).
Clutch Size: 4 to 6 (Goodwin 1982; Restall 1997); mean clutch size at 6 California nests was 5.5 (Smithson 1997).
Broods/Year: 2, sometimes 3 to 4 (Restall 1997); double broods have been recorded in California (Smithson 1997).
Incubation Period: 14 days (Restall 1997).
Fledging Period: 18 to 19 days (Restall 1997).
Age at First Breeding: At least occasionally breeds at less than 1 year (Smithson, pers. comm.).
California Population Size and Trends: Los Angeles and Orange County population conservatively estimated at 450 (Smithson 1997). Not mentioned by Hardy (1973); possible establishment in early 1990s first noted by Johnson and Garrett (1994). Pest potential and occasional appearance in California pet shops noted by 1987 (J. Hitchcock, pers. comm.). Numbers appear to be rapidly expanding in lowland southern California.

Orange Bishop (*Euplectes franciscanus*) - "Northern Red Bishop"
Native Range and Habitat: Sub-Saharan Africa, from Senegal east to Ethiopia and south to the equator (Macworth-Praed and Grant 1960; a related species (Red Bishop, *Euplectes orix*) occurs farther south in Africa. Tall grassland, cultivated areas, especially near water and marshes (Zimmerman et al. 1996).
Distribution in California: Riverbottom areas of coastal lowlands, mainly in Los Angeles and Orange counties (Johnson and Garrett 1994; Smithson 1997), but also locally from Santa Barbara County to San Diego County, and in the San Francisco Bay area. Most numerous in the Los Angeles and San Gabriel River systems.
Habitat in California: Weedy areas, flood control basins, river channels, especially where dominated by *Echinochloa* grass (Smithson 1997).
Elevation Range: From lowlands to at least 1,000 m in Africa (Zimmerman et al. 1996); in California mainly found from sea level to 800 m.
Primary Diet: Grass seeds, especially *Echinochloa*, *Cortaderia*, and *Paspalum dilatatum* (Smithson 1997);

also noted feeding on emergent aquatic vegetation (*Polygonum*) and on cocklebur (*Xanthium*) (Garrett, pers. obs.). Visits seed feeders, mainly in late winter and spring (Smithson 1997; Garrett, pers. obs.).
Foraging Substrate and Techniques: Grass and weed stems, ground, seed feeders.
Breeding Season: Breeding in southern California is mainly August to November, and appears to be tied to the seeding of *Echinochloa* grass and other important food items (Smithson 1997).
Nest Site and Materials: Nest is placed in clumps of *Echinochloa* grass or, more rarely, pampas grass (*Cortaderia*) or giant reed (*Arundo donax*) (Smithson 1997). Probably also placed in other weedy or marshy vegetation in flood control basins, river channels. Mean nest height in southern California was 1.1 m (n=5; Smithson 1997). The ball-shaped nest is woven from grass blades and stems. Males build multiple nests; females line those that are ultimately used for nesting (Craig 1980, 1982).
Mating System: Polygymous; males may hold harems of up to 6 females (Craig 1982).
Clutch Size: 2 to 3 in southern California (Smithson 1997). Mean clutch size of related *E. orix* in South Africa is 2.7 (n=1,060; Maclean 1985).
Broods/Year: Possibly only 1 in California (Smithson 1997).
Incubation Period: 12 to 13 days in closely related *E. orix* in South Africa (Maclean 1985).
Fledging Period: 12 to 16 days in related *E. orix* in South Africa (Maclean 1985).
Age at First Breeding: Probably 2 years (Craig 1982).
California Population Size and Trends: Current population in Los Angeles and San Gabriel River drainages (Los Angeles and Orange counties) conservatively estimated at 400 (Smithson 1997). Occasional sightings date back at least to the 1970s (Garrett, pers. obs.), but most rapid increases have been in the 1990s. Sizes and trends of small populations elsewhere in California unknown.

DISCUSSION

The future of the populations outlined above is hard to predict; many factors (physical stress, disease, or ecological interactions) could impact populations. On the other hand, some of these populations could continue to expand into available habitat, and suitable habitats themselves could expand with increasing urbanization. In the case of the Eurasian Collared-Dove, the long-established (but also introduced) Spotted Dove might provide an ecological barrier or might itself decline with a growing Collared-Dove population. Additionally, we do not know at present how closely-related species now in "artificial" sympatry will coexist, and whether interbreeding might occur; examples of such species pairs are Red-crowned and Lilac-crowned parrots, White-winged and Yellow-chevroned parakeets, and Mitred and Red-masked Parakeets.

Current knowledge of the ecological and economic impacts of these species is limited; some (such as the Nutmeg Mannikin and Black-hooded Parakeets) are known to depredate crops in parts of the native or introduced range. Currently the California populations discussed above appear to have little, if any, impact on economically important crops, but may have very local impact on gardens and small orchards. Their restriction to urban and suburban habitats minimizes agricultural impacts, as well as deleterious interactions with native birds such as cavity nesters, frugivores, and granivores.

Standard bird censuses (BBS, CBC) do not adequately monitor many introduced bird species (Johnson and Garrett 1994). Birders, consultants, and agency biologists need to become familiar with the field identification of non-native (as well as native) species. Ongoing Breeding Bird Atlas work is filling in some distributional gaps. The primary need, however, is for focused monitoring. Little is known of the natural history of these species in their introduced range, and information from their native ranges (if even available) may not always be applicable to the area. Monitoring schemes should not only detail geographical distribution and population sizes, but should seek to examine breeding phenology and requirements, reproductive success, movements, diet, and interactions with native (and other non-native) species.

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MONK PARAKEETS IN THE UNITED STATES: POPULATION GROWTH AND REGIONAL PATTERNS OF DISTRIBUTION

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ABSTRACT: Records from Christmas Bird Counts were summarized to assess population growth of the Monk Parakeet (*Myiopsitta monachus*) in the United States from 1975 to 1996. Population growth over this period fits an exponential model of population growth with a current annual rate of increase of 12.9% and a doubling time of 5.4 years. Since 1990, however, population growth on a national scale has slowed considerably, suggesting that the species may be approaching a carrying capacity. In contrast to the results across the entire United States, the population of Monk Parakeets in northeastern Illinois has dramatically increased in numbers within the last decade. In this region, the Hyde Park, Chicago population appears to be acting as a source from which other areas are colonized. The Monk Parakeet is known to have caused damage to fruit crops in Florida, and they can be a nuisance species to local utility companies when they build their nests on power transformers. Nevertheless, such damage is highly localized and, on a national scale, there is no evidence to date that Monk Parakeets should be considered a pest species and subject to widespread control. The initiation of detailed studies of a banded population of this species is recommended.

KEY WORDS: Monk Parakeets, introduced species, parrots, population growth, exponential growth

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INTRODUCTION

Introduced and naturalized parrots are an increasingly common part of local avifaunas in some regions in the United States. In southern California, for example, there are now 10 species of naturalized parrots and population estimates put the numbers of individuals at 2,500 to 3,000 (all species combined; Garrett 1997). As another example, in Florida, on the 1996-1997 Christmas Bird Count a total of 1,761 individuals of 16 species of parrots were reported. It is not yet known how many of these 16 species are naturalized in Florida but it is likely to be many of them.

Without exception, the most abundant and widely distributed of the naturalized parrots in the United States is the Monk Parakeet (*Myiopsitta monachus*). This species became naturalized in the United States in the late 1960s (Lever 1987) and is now resident in 76 localities in 15 states and is experiencing exponential population growth (Van Bael and Pruett-Jones 1996). Monk Parakeets also have become naturalized in Europe and are increasing in numbers there as well (Sol et al. 1997).

There is greater concern about the Monk Parakeet than other naturalized parrots because of the possibility that it may become an agricultural pest, as it is reported to be in its native range (Bump 1971; Bucher and Bedano 1976; but see Bucher 1984). The Monk Parakeet was the focus of an eradication campaign by the United States Fish and Wildlife Service (USFWS) in the 1970s, a program that reduced its population by approximately one-half (Neidermyer and Hickey 1977). The Monk Parakeet is also of interest from a behavioral perspective because it is the only species of parrot to build its own nest and exhibit cooperative breeding (Sol et al. 1997; Eberhard 1998; Spreyer and Bucher 1998).

In this paper, the authors analyze trends in population growth of the Monk Parakeet in the United States from the period 1975 to 1996, population growth in one specific community, Hyde Park, Chicago, and the regional pattern of distribution in northeastern Illinois. This work updates the surveys conducted by Hyman and Pruett-Jones (1995) and Van Bael and Pruett-Jones (1996), extending their analyses up to 1996. The authors also discuss evidence relating to the status of the Monk Parakeet as a pest species and argue that such designation is unwarranted at the national level.

METHODS

Population Censuses

The use of Christmas Bird Counts (CBC) records published in American Birds (now Field Notes) extends the analysis presented in Van Bael and Pruett-Jones (1996). Briefly, CBC records from the 1975-1976 count (the year following the end of the USFWS control program) to the 1996-1997 count were summarized. In examining these data for the 1972-1973, 1981-1982, 1986-1987, and 1992-1993 through the 1996-1997 counts, records were checked for every reporting locality in the United States. For the intervening years, records were checked for every locality in all states that reported at least one Monk Parakeet during at least one of the counts listed above. For each CBC locality, the total number of birds reported as well as the number of party hours was noted. For some years, Monk Parakeets were recorded during the "count week" at a given locality, but no birds were actually recorded on the formal count day. In tabulating numbers of individuals recorded, "count week" records were counted as one parakeet at that given locality.

The rate of population growth was calculated using the standard equation defining exponential growth $N_{t+1} = N_t e^{rt}$ where N_{t+1} is the population size at time t+1, N_t is the population size at time t, r is the rate of population growth, t is the time interval, and e is the natural logarithm base. To calculate the intrinsic rate of population growth, r, this equation can be rewritten as $r = (\ln N_{t+1} - \ln Nt)/t$. For each one-year time interval beginning in 1975 (the year the USFWS control program ended) r was calculated. A plot of r versus population size indicates whether a population is expanding, declining, or has reached a stable equilibrium size. To calculate the time interval for a population to double in size, the equation above defining r can be rewritten as $t = \ln 2/r$.

Regional Distribution

To quantify regional distribution and abundance, during January and February 1998 the authors attempted to locate all Monk Parakeet nests in the Hyde Park community of Chicago, as well as in northeastern Illinois, from the Wisconsin border to the north to the Indiana border to the southeast. Known sites, such as the Hyde Park area, were searched systematically and thoroughly. Other sites were discovered through data collected on Christmas Bird Counts, and correspondence with Chicago area birdwatchers. All sites reported were visited and the number of nesting structures and nest chambers recorded. Although an attempt was made to find every single nesting structure on the surveys, the limited time spent in some areas prevented accurate counts of individual birds.

In keeping with the terminology introduced by Hyman and Pruett-Jones (1995), the authors refer to a nesting structure as a stick structure containing one or more chambers, and a nesting chamber as a cavity that birds were known or suspected to use for nesting or roosting.

RESULTS

Population Growth

When viewed over the entire 22 year period, 1975 to 1996, population growth of the Monk Parakeet in the United States has been positive and exponential in nature (Figure 1, Figure 2, Table 1). There has, however, been considerable yearly variation in growth rates. Population data for three periods were analyzed separately as shown in Figure 1 (Period 1, 1975 to 1981; Period 2, 1982 to 1989; Period 3, 1990 to 1996; these periods were determined by visual inspection of the data). The results of the separate analyses are shown in Figure 1 and Table 1.

During Period 1, immediately after the USFWS control program ended, the Monk Parakeet experienced marginally positive growth (Table 1). This trend ended abruptly in the early 1980s and was followed by phenomenal growth rates for almost a decade (Period 2) in which the population increased on average 33.6% per year (Table 1). Lastly, during the 1990s, population growth slowed considerably, and was not statistically significant over time (Figure 1). The rates of population growth during Periods 2 and 3 (the slopes of the regressions) were significantly different (ANCOVA, $F = 20.07$, $P < 0.001$).

A plot of the intrinsic rate of population growth, r, versus population size (Figure 2) reveals the same pattern of recent declining population growth shown in Figure 1. Over the last seven years, from 1990 to 1996, the intrinsic rate of growth has been negative or very close to zero for five of these years (Figure 2).

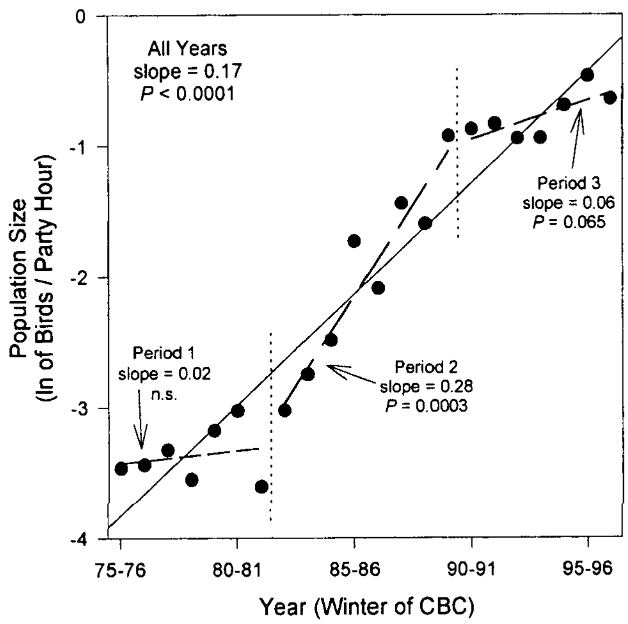

Figure 1. Population growth of the Monk Parakeet in the United States, 1975 to 1996. Shown is the regression of population size (ln of birds/party hours reported on annual Christmas Bird Counts) by year for the entire period (solid line) and for three separate periods (hatched lines). The vertical dotted lines indicate the separation of the periods.

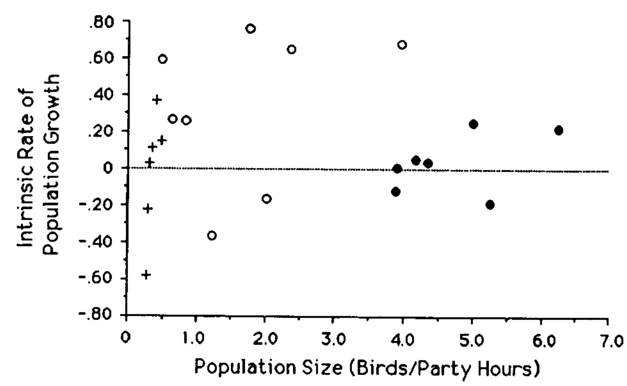

Figure 2. Plot of intrinsic rate of population growth of Monk Parakeets in the United States for the period 1975 to 1996. The different symbols refer to the different periods illustrated in Figure 1 and listed in Table 1; crosses refer to the years in Period 1, open circles the years in Period 2, and the solid dots the years in Period 3.

Table 1. Population growth of Monk Parakeets in the United States, 1975 to 1996.

Period	Number of Years	Regression Slope	F	R^2	P	$r^{(1)}$	$t^{(2)}$
Overall	22	0.17	235.13	0.918	<0.0001	0.129	5.4
1 (1975 to 1981)	7	0.02	0.21	0.150	0.6641	0.023	30.1
2 (1982 to 1989)	8	0.28	55.66	0.886	0.0003	0.336	2.1
3 (1990 to 1996)	7	0.06	5.57	0.432	0.0647	0.040	17.4

(1)The intrinsic rate, r, of population growth.
(2)The time, t, for the population to double in size.

Within the Hyde Park, Chicago community, population growth of Monk Parakeets has been dramatic, and opposite the recent trend for the nation as a whole. In 1992, Hyman and Pruett-Jones (1995) counted 29 nesting chambers and a total of 64 birds. In 1993, approximately 95 birds were counted. In 1995, 85 nesting chambers were counted for an approximate population size of 170. In January 1997, 104 nesting chambers were counted for an approximate population size of 208 birds. The increase from 64 birds in 1992 to approximately 200 birds in 1997 represents an annual population growth rate of 22.8% with a population doubling time of just 3.05 years.

Regional Distribution

In northeastern Illinois, Monk Parakeets nest in six different sites stretching 150 km along the western shore of Lake Michigan (Figure 3). At two additional areas, Carol Stream and Addison, birds are regularly seen but no nesting structures are known. In one of these areas, Carol Stream, the absence of nests is recent, and due to both destruction of nests by the local utility company and to the natural felling by storm of a tree in which a large nest was located. With the exception of Zion (where there is one historical nest that is not currently active), all of the areas where the parakeets are nesting support multiple nesting structures and several to many pairs of birds (Figure 3). The dispersion of nests statistically was not analyzed, but it is evident from visual inspection that the dispersion is highly clumped (Figure 3).

DISCUSSION

The conclusion that one reaches about population growth of Monk Parakeets depends on the time frame and region under consideration. From 1975 to 1996, the population increased exponentially in the United States (Figure 1). Nevertheless, records for the last seven years (1990 to 1996) reveal that population growth has slowed considerably, and no longer shows a statistically significant increase (Figure 1).

Within one particular community, Hyde Park, Chicago, however, population growth has continued unabated, especially over the last five years. The observed population growth in Hyde Park has not been mirrored by continued increases in the numbers of birds reported on Chicago area Christmas Bird Counts (CBC). These numbers have fluctuated between 5 to 35 since 1990. The reason for this difference is that the CBC count circles do not encompass the Hyde Park community.

This discrepancy in counts (actual versus CBC records) for the Chicago area illustrates the magnitude of the error of CBC data in estimating total population size. The 1996-1997 count of 1,804 individuals in the United States could be as little as 5 to 10% of the total number of parakeets. For the Chicago area, the CBC counts have counted between 5 to 20% (depending on the year) of the total number of birds actually known in Hyde Park.

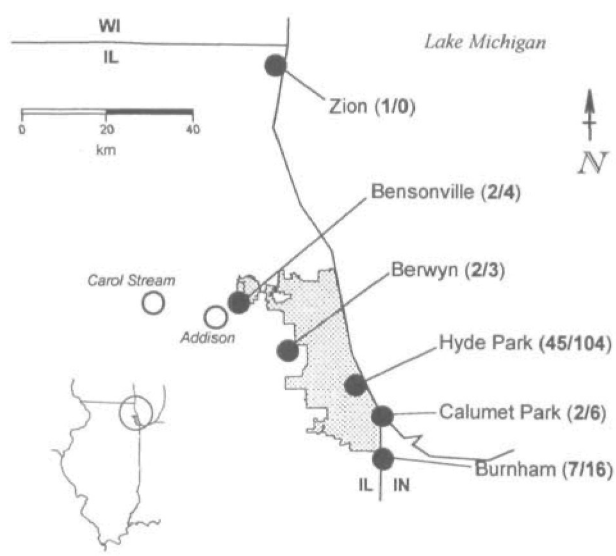

Figure 3. Distribution of Monk Parakeets in northeastern Illinois. Inset shows a map of Illinois and the region covered, from Wisconsin to the north to Indiana to the southeast. Solid dots indicate sites where Monk Parakeet nests are known (numbers in parentheses indicate the number of nesting structures/number of nest chambers at that site; see text for definition of terms). Open circles indicates sites where birds are known to occur but at which no nests are currently known.

In northeastern Illinois, the distribution of parakeets appears to be regionally clumped. The abundance of birds at different localities suggests that the Hyde Park area is acting as a source population for the other colonies. As one moves away from Hyde Park, the abundance of parakeets drops.

Concern over the population of Monk Parakeets in the United States stems from their reputation as an agricultural pest in Argentina. There is, however, an increasing belief that this reputation is overstated and undocumented (Bucher 1984; Spreyer and Bucher 1998). Within the United States, the Monk Parakeet is known to cause localized damage to fruit crops in Florida (A. Van Doorn, pers. comm.) and is a nuisance species in many areas because of the tendency of birds to build their nests on power transformers (personal observations). In Hyde Park, Chicago a large nest built on a power transformer caused an electrical short and a resulting fire. The local utility company removed this nest. The authors have been told through correspondence that utility companies in Florida and Texas regularly destroy the nests of Monk Parakeets that are built on transformers or, in some cases, telephone poles.

Such problems as localized damage to crops and nests on power transformers are significant, but should not be the basis of widespread concern. These problems can be appropriately and efficiently dealt with on a local level and do not, in the authors' opinion, justify state-wide or national policies of eradication or control.

Nevertheless, detailed studies on foraging habits, home range, and dispersal of Monk Parakeets have yet to be conducted in the United States and must be undertaken to accurately assess the potential threat of the species. That the Monk Parakeet is becoming a common species in many parts of the United States is no longer in doubt. Whether it will be viewed as a benign and welcome addition to local avifaunas, or as a serious pest species has not yet been determined.

ACKNOWLEDGMENTS

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THE U.S. AIR FORCE BIRD AVOIDANCE MODEL

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Each year, the United States Air Force (USAF) reports approximately 3,000 bird strikes to its aircraft. These incidents cost nearly $50 million on average. In the last decade, the Air Force has suffered the loss of 14 aircraft and 33 aircrew fatalities. The other services report higher rates of strikes per flying hour and suffer similar losses. Civilian aircraft are not immune to this problem, and U.S. airlines report nearly $100 million in annual losses. Most bird strikes occur around airfields where habitat management, bird dispersal techniques, and active population control can be employed. For military aircraft, however, the majority of catastrophic incidents occur on high-speed, low-level, and range missions where bird control is not possible. The only alternative in these environments is to avoid known bird concentrations. This is where the Bird Avoidance Model (BAM) comes into play.

The BAM is a Geographic Information System (GIS) based program that integrates historical information on bird distributions and abundances with various geographic and environmental factors. It creates graphic risk surfaces for determining the relative degree of hazard for any location in the Continental U.S. Data on bird populations and movement patterns come from numerous government and private sources and is the result of, literally, millions of hours of field work from biologists, refuge managers, amateur bird watchers, and volunteers. Thirty years of data from over 10,000 locations throughout the country are evaluated and used as the basis for the model. Interpolation algorithms fill in the gaps between the surveyed locations so that each square kilometer of the U.S. has a unique risk value assigned.

The initial version of the model includes over 50 species considered most hazardous to flight operations. Large birds, such as waterfowl and raptors, and flocking species, such as blackbirds and gulls, constitute the greatest threat. A risk surface is generated using the available data and normalized by body weight for each species. The individual risk surfaces are then cumulatively added and a total risk calculated. Data are available for each two-week interval of the year and for various daily time periods. A color-coded graphic display, in a GIS map format, is available for each data layer, and the scale of coverage can be selected by the user.

Specifically, the model relies on large historical data sets, such as the Christmas Bird Count (CBC) and the Breeding Bird Survey (BBS), as baseline estimates of bird abundance and distribution. These data are available in grid maps at one kilometer resolution. All other data sets are spatially registered and matched to this resolution. Much work was done to develop a conversion factor to equate the CBC and BBS on a relative scale so that the risk of bird strikes could be compared for these two times of the year. Information from migration counts and arrival and departure dates for species of interest at hundreds of wildlife refuges was used to interpolate the movement of populations during the intervening periods. Daily activity patterns were also modeled for each species so that the risk surfaces vary by time of day as well as seasonally. The user can, thus, select the geographic location, time of year, and time of day when planning a flight profile.

The user interface for the new BAM is a simple, menu-driven, PIC-based program that allows flight planners, route designers, and aircrew to select the geographic location, time of year, and time of day that they desire to fly a particular route. Relative risks for each operation can be assessed by comparing routes to each other or by comparing various temporal alternatives on individual routes. Safest times and locations can then be selected by the user. The model also has numerous geographic and environmental data sets that can be overlaid on the bird risk surface. For example, the user can zoom in on a portion of the country, display the bird risk, and overlay roads, airports, aircraft operating areas, terrain maps, land uses, or a variety of climatic information such as temperature or precipitation on the computer display.

The model will be distributed by the Air Force Bird Aircraft Strike Hazard (BASH) Team to various users throughout the country. While the program and data needed to generate the Bird Avoidance Model require enormous amounts of computer space, the products of the model will be available on CD for the ultimate users. It is anticipated that copies will be available to anyone with a PC and the commercial software needed to run the program.

The new BAM will provide a tremendous planning tool for the aviation community to reduce the incidence of bird strikes to aircraft. Organizations employing early versions of the model have reported reductions in the bird strike rates of as much as 70%. The new model will provide much more data and at a resolution orders of magnitude better than the existing models.

The work is not done, however. We need to field test the model, refine some of the data layers, expand to areas outside the U.S. and, ultimately, provide near-real time updates to the model using technologies such as doppler radars and satellite telemetry. A current collaboration is underway to extend this technique to countries in Europe and the Middle East. The Department of Biology at the Air Force Academy, in collaboration with other departments and agencies, will continue to participate in the future as long as sponsoring agencies continue their support of these efforts. Ultimately, we hope to make the skies a bit safer for those who share them with the birds.

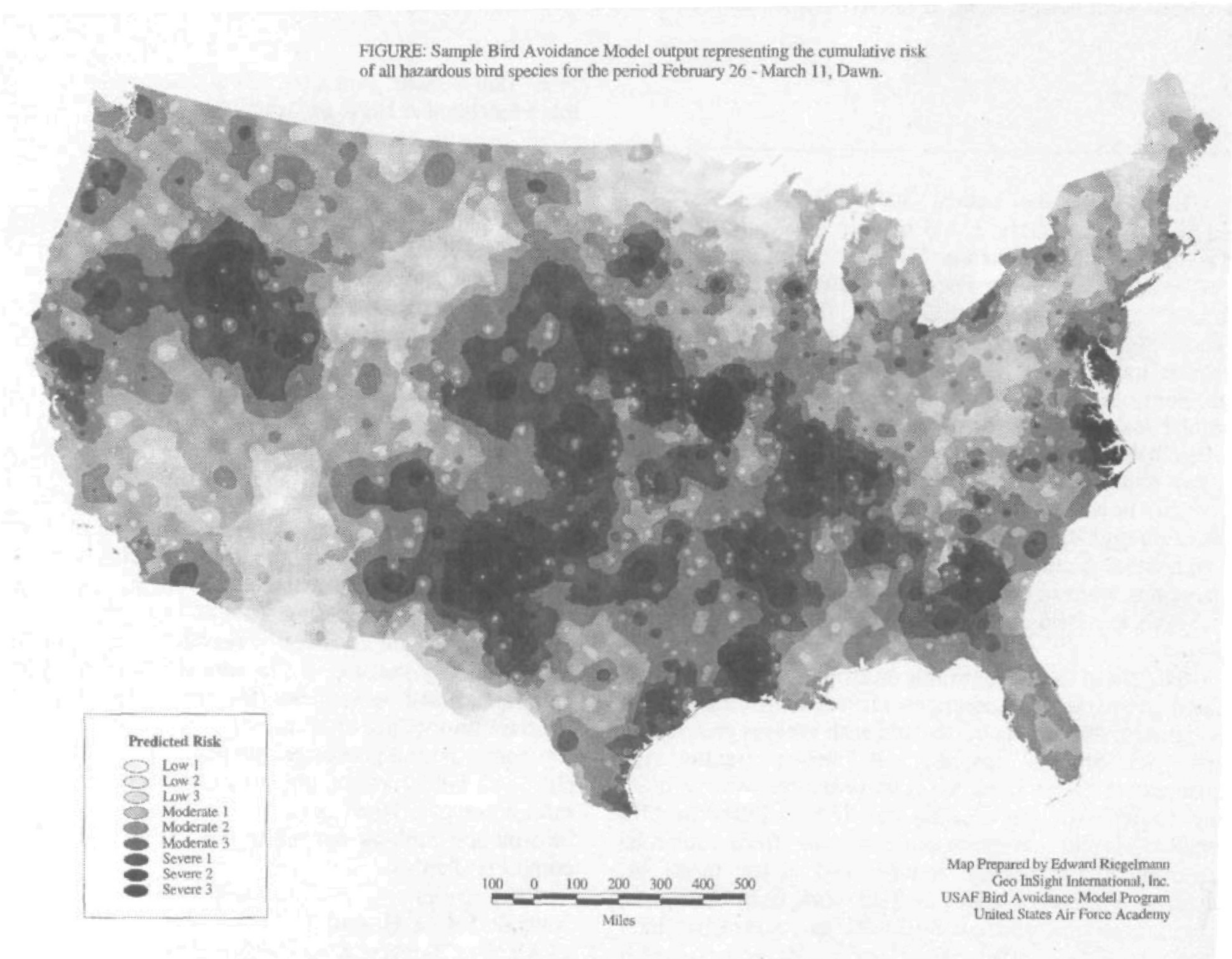
FIGURE: Sample Bird Avoidance Model output representing the cumulative risk of all hazardous bird species for the period February 26 - March 11, Dawn.
Predicted Risk
Low 1
Low 2
Low 3
Moderate 1
Moderate 2
Moderate 3
Severe 1
Severe 2
Severe 3
100 0 100 200 300 400 500
Miles
Map Prepared by Edward Riegelmann
Geo InSight International, Inc.
USAF Bird Avoidance Model Program
United States Air Force Academy

Figure 1.

CONTAINMENT BASINS AND BIRD EXCLUSION—A HISTORICAL PERSPECTIVE

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ABSTRACT: Most facility engineers with responsibility for hazing birds on containment basins use agricultural crop protection techniques. This approach is appropriate for basins with non-hazardous solutions. Basins containing toxic solutions require an entirely different approach. Detoxification, or exclusion with floating membranes, netting or Bird Balls™ are the best options.

KEY WORDS: Bird control, bird hazing, containment basin, ponding basin, floating membranes, netting

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INTRODUCTION

Conflicts between birds and the operators of ponding basins have always been challenging. Facility engineers that maintain potable water storage reservoirs occasionally have their hands full attempting to exclude gulls, ducks and geese. Contamination levels from the feces of hundreds of these large birds congregating on a drinking water impoundment reservoir have been the impetus for initiating many bird hazing programs. A moderate degree of success in diminished bird numbers is accepted as an accomplishment and a job well done.

Conflicts between birds and the operators of large tailings ponds associated with the processing of soda ash is a more serious issue relative to enforcement of the Migratory Bird Treaty Act. In this industry, the waterfowl and shore birds using the artificial ponds may die from exposure. The fine powdery-like particles in the water dry on the birds plumage, stripping the protective oil from the feathers. Exclusion is not currently feasible on a 100-acre tailings pond so this industry relies on harassment with air boats, sound systems and sophisticated radar tracking devices that launch a battery of pyrotechniques when birds come into the alarm zone.

Conflicts between birds and industrial containment basins containing toxic liquids has become a high stake issue regarding enforcement of the Migratory Bird Treaty Act. In many instances the bird loss rates are much too high in the eyes of industry as well as the regulatory agencies. There are not many facility engineers who like to see dead ducks floating on their ponding basin. But until the last few years, there were not many viable options for excluding waterfowl from basins containing toxic solutions.

The most recent technical breakthroughs for excluding birds from containment basins have been developed as a result of the needs within the precious metals mining industry. The last 10 to 15 years have been a gold rush era in the United States with the State of Nevada becoming one of the top gold producers in the world. This is a result of technical developments in the extraction of microscopic gold with sodium cyanide. The process is called heap leaching.

HEAP LEACHING DEFINED

This mining process uses low grade ores down to approximately 0.02 ounces of gold per ton. Milling techniques are used for high grade ores but many mines use both techniques with multiple basins containing sodium cyanide. Robert Hallock (retired U.S. Fish & Wildlife Service) has written one of the most succinct definitions of heap leaching. He states that "Typical heap leaching operations involve the placing of ore on an impermeable lined pad. Buffered cyanide solutions are distributed across the surface of the ore (heaps). The solution leaches gold and is collected from the base of the heap on the lined pad. From the pad it is transported to a plastic lined pregnant solution pond (the solution which bears the gold). The gold is then removed from the pregnant solution in an enclosed extraction system. The solution then passes to the barren solution pond. Here, cyanide concentrations are restored to the level necessary for efficient leaching. This barren solution is then recycled across the heaps. Thus solution movement is a circular process.

Cyanide concentrations are highest in the barren pond and the solutions being applied to the surface of the heaps, and concentrations are lower in the collection systems at the base of the heaps and the pregnant solution ponds. Variable amounts of cyanide are consumed during the leaching phase. The typical operation also has an event pond to contain excess cyanide solutions from the heaps during high precipitation events. Cyanide concentrations in this type of pond are highly variable. There are many variations of this typical heap leaching process, some of which diminish or eliminate migratory bird mortality. The best methods are those that deny migratory birds access to cyanide solutions.

Combined Pad/Pond Facility

The combined pad/pond technique differs from the typical heap leach facility in that the pad is constructed in the form of a reservoir or basin. The heaps are then placed within this reservoir for leaching. The reservoir is sized to allow the porous spaces within the ore heap to serve as space for both the pregnant solutions and emergency holding of additional water that could occur during unusual precipitation events. A series of collection lines and a sump pump are provided to recover the pregnant solutions from the bottom of the reservoir. With this technique there is no exposed pregnant solution pond nor are there collection channels at the heap margins. Savings in cyanide and water may compensate for any additional construction expenses. This technique may be limited by the extent of clay in the ore which could block solution movement and extraction efficiency.

Barren or Pregnant Solution Tanks

Several mine operators have chosen steel tanks in place of traditional exposed, excavated, plastic lined barren and/or pregnant solution ponds. Because the solutions are in steel tanks, they are not attractive to birds. Some tanks are enclosed or indoors and completely unavailable to birds or other wildlife. Common to all observed mines using this technique is a need for an emergency precipitation event pond which may contain cyanide on an irregular basis. As with the combined pad/pond technique, this technique has the potential to conserve both cyanide and water. In addition it allows solution temperature control during winter operations. One or more solution pond(s) may be eliminated and, to the extent this occurs exposure to birds and other wildlife is reduced" (Hallock 1990).

The large number of migrating birds that use these leachate basins as a loafing site has astounded many inside and outside the mining industry. And this seems to be the case even at mines located outside the U.S. because even international mine operators insist on engineering bird exclusion systems into the specifications as part of the bidding process.

DEVELOPMENT OF CONTROL TECHNIQUES

Hazing

Regardless of the industry, the approach to controlling birds usually starts with what we have seen done in the agricultural setting. Thus, we have overworked purchasing agents looking for a source of flagging, pennants, stretch wires, balloons, pinwheels, reflectors, flashing lights, high intensity spot lights, battery operated radios, sirens, horns, liquid dyes and radio controlled boats and airplanes.

Once the products are acquired, we have high-paid engineers and crews installing and learning how to use these devices. In time it is observed that if birds really want to set down on a ponding basin they will do so regardless of colors, flapping fragments or buzzing bombardments. This empirical process leads us into a second phase of field trials. Agricultural bulletins tell us that one should use a combination of techniques. So we install propane cannons, human effigies, crucified ducks, helium filled raptor balloons, and fire off pyrotechnic devices when the ducks set their wings with determination.

This is not said to criticize bird control research in agriculture. Indeed, we need a data base from which to work. Three examples of good field research that have given hope and direction are the use of reflecting tapes to repel blackbirds in grain crops (Dolbeer et al. 1986); the use of propane cannons, color cueing, and herding as a method of hazing waterfowl in grain crops (Knittle and Porter 1988); and the use of stretch wires to deter or repel birds (Pochop et al. 1990).

Neither are we making a statement about the field work done by operators of containment basins in any industry. After all it has been documented that some of the hazing devices mentioned above deter or repel select species under certain weather and site specific conditions; for example, the use of mechanical hazing devices on chemical evaporation ponds (June 1979); human effigies at tailings ponds (Yonge 1979); sound systems on containment basins (Martin 1980); the use of hazing devices and associated costs at leachate ponds (Sturgess et al. 1989); the effects of sound devices on gulls and cormorants in a confined space (Martin and Martin 1984); electronic bird control in tailings ponds (Patton 1996).

The point is that a distinction must be drawn between the use of hazing to deter birds feeding on a crop and the use of hazing to exclude migratory waterfowl from landing on a hazardous material. In fairness, it must be said that during the infancy of heap leach mining no one dreamed that the containment basins would attract waterfowl. At many sites no one had seen many birds, let alone waterfowl. All too soon it became apparent that these basins located in remote desert regions were a welcomed loafing site for flight-weary, migrating waterfowl. Hopefully, history will not repeat itself when similar circumstances arise in the future.

The result was a scramble to keep waterfowl off the basins. The environmental engineers and plant operators were testing hazing devices to the limit and trying to figure out how to use bird netting to exclude birds from landing in the basins. It did not take long to realize that the only successful system would be a barrier to cover over the top of the basin. Detoxification of solutions has not proved to be user friendly. Non-exposed solution systems are currently being used and may prove to become the standard in the future.

Exclusion

The first attempts at netting containment basins were done with lightweight, agricultural netting and 1/8-inch cable spaced at 20-foot intervals. The perimeter cable anchors were "T" posts driven into the ground. If the first 50-mile an hour wind did not tear the netting off, then the first heavy spring snow collapsed the entire system. Obviously, engineered specifications would be required.

Cable size had to be increased to accommodate break strengths of over 10,000 lbs. The use of PVC coated 7 x 19 strand cable with thimbles on all terminal ends became a necessity. The standard heavy duty cable system with a five foot grid pattern presented some challenges for perimeter anchoring.

Traditional perimeter anchoring systems of pipe and concrete were costly and had unacceptable failure rates. Soil conditions around a typical basin changed dramatically from sand to solid rock, with everything else in between. Sudden spring rainstorms would saturate the soil and allow the cable tension to pull over the pipe and concrete anchoring posts. In time, Duckbills became the industry standard for perimeter anchoring.

The Duckbill Principle

The Duckbill anchor works very much like a toggle bolt. The anchor body is driven into the soil with a re-useable drive road. Once the anchor body is placed to the proper depth, the drive rod is removed. A backward pull on the cable then rotates the anchor body in the ground until it is perpendicular to the cable. This is called load-locking the anchor. Because the Duckbill is usually driven into the earth, it is actually compacting the soil, not disturbing it. As the anchor is load-locked, it cuts through the compacted soil into undisturbed soil and further compacts the soil above the anchor. As the soil above the anchor is compacted from below it forms an inverted cone of compact soil. This is called a cone of resistance.

One of the most important features of the Duckbill anchoring concept is the ability to proof-test the anchor during normal installation. The load locking operation can be a proof-test of the anchor. By measuring the force required to load-lock the anchor, the installer knows the actual holding capacity of the installation.

Soils

Anchor holding capacity will vary in the different classes of soils. More capacity can be expected in the numerically lower classes and less capacity in the higher classes. Knowing the type of soil does not always mean that the class is known. For example, a clay material can have a class ranging from 4 to 8 depending on whether the material is very stiff to hard or soft to very soft. Water content will also affect classification. Similarly, cohesionless soils such as sands and gravels have a wide range depending upon the density or compactness of the material.

There are various ways of testing soils. A torque probe is the best for quick classification in the field. Core samples are the best for detailed classification, but are expensive and take time to obtain the test results. Generally, resistance to driving the Duckbill is a good "seat of the pants" indicator of soil class. Stiff resistance will normally result in positive anchoring. If the anchor drives very easily, the soil is soft and steps should be taken to assure adequate capacity. Keep in mind that simple proof-loading will verify the capacity of the anchor in any soil class.

The anchors are rated in an average (class 5) soil condition. Again, higher capacities can be expected in harder soils and lower capacities in softer soils. The rating is mainly useful as a reference for anchor selection. Proof-loading is the only way to insure the exact capacity of each installation. This is true for all anchors on the market today.

Special Soils Considerations

Soft Soils: In areas where the soil proves to be softer than normal, steps should be taken to assure the capacity of the anchor. Proof-loading is especially useful in soft soils. Guesswork as to the capacity is eliminated. The installer will know immediately if the anchor point is adequate or if further steps are necessary. Backfilling and tamping the hole behind the anchor will yield somewhat higher capacity in most soft soils. Fill and tamp the hole in 3 inch lifts prior to load locking the anchor. Another option is to drive the anchor deeper in an effort to penetrate a harder layer of soil. Larger anchors may need to be placed to achieve the required load. As a last resort, a number of anchors may be placed in a cluster and bridled together to form one point.

Hard Soils and Rock: If excessive resistance to driving occurs, it may be necessary to drill a hole for anchor placement. If the anchor stops moving and is subjected to excessive pounding (especially from power equipment), metal fatigue can occur and the anchor body can fracture. The Duckbill anchor may be placed in a pre-drilled hole in hard dirt or rock and achieve very good results. Hand augers and gasoline or hydraulic powered earth drills can be used to form the hole.

Table 1. Classes of Soils and Prove Values

Class	Description	Probe Value
1	Solid Bedrock	--
2	Dense Clay; Compact Gravel Dense Fine Sand; Laminated Rock; Slate, Schist; Sandstone	Over 600 in./lbs.
3	Shale; Broken Bedrock; Hardpan; Compact Gravel Clay Mixtures	500-600 in./lbs.
4	Gravel; Compact Gravel and Sand; Claypen	400-500 in./lbs.
5	Medium-Firm Clay; Loose Standard Gravel; Compact Coarse Sand	300-400 in./lbs.
6	Medium-Firm Clay; Loose Coarse Sand; Clayey Silt; Compact Fine Sand	200-300 in./lbs.
7	Fill; Loose Fine Sand; Wet Clays; Silt	100-200 in./lbs.
8	Swamp; Marsh; Saturated Silt; Humus	Under 100 in./lbs.

Table Provided by A. B. Chance.

Floating Membranes

Pilot studies in the late 1950s showed that the principle of the floating cover had merit but it took an actual full scale installation to prove that the principle would work on large reservoirs as well as on small scale experimental models. The first commercial floating cover was installed in California in 1964. It consisted of a membrane and a parallel arrangement of 4" by 12" flexi-rigid, closed cell polyethylene floats installed on the underside of the cover with the float ends terminating at the toe of the slope. The termination point determined the inside boundary of the rainwater collection canal while the outer boundary was the top anchor system itself. Vertical wall tanks could also utilize this system in which case the floats terminated in standard fixed distances from the wall to define rainwater collection canals of precalculated capacity. This original floating cover design was patented in 1967 and since then hundreds, if not thousands, of these type covers have been installed throughout the world.

The first floating cover had no weights, cables or columns in the design. It was a stress-free system. Since columns and other support mechanisms added weight (and cost) to the cover, these components were not used. A second feature of the floating cover was its ability to isolate itself from stress due to seismic loadings. In contrast to floating covers, structural covers do not have a natural immunity to loadings of this type since their high inertia must be controlled by the design of proper reinforcement which increases their cost.

The initial floating cover patents in 1967 prompted a flurry of activity in this field and the first variation from a stress-free cover was introduced in Canada in 1974. It was the first stressed cover and depended on a series of cables to provide tension on the cover.

The second variation from the stress-free cover was introduced in 1976. Featuring a continuous weighted tube centered between a set of two parallel rows of floats, the arrangement pulls excess material into a rainwater collection canal and at the same time divides the cover into segments. The location of the canal can be varied depending on the effect the designer is trying to achieve. Rainwater removal is through the reservoir cover membrane, down through the impounded water and out the embankment or wall. The water can also be pumped over the top of the reservoir into an overflow structure.

The use of floating membranes to exclude waterfowl has not been cost effective compared with netting or bird balls.

Netting Selection

Light weight (4 to 8 lbs./MSF with nominal BS 20 to 30 lbs/strand) extruded netting will hold together for a maximum of three years under intense sunlight as long as snow loading is minimal (1 to 3 lbs./sq. ft) and winds do not go over 25 to 35 mph. Light weight systems require cable to be laced internally.

Heavy woven netting (12 to 16 lbs./MSF with nominal BS 65 to 85 lbs/strand) lasts a minimum of five or more years if installed properly. This netting requires the heavy duty cable and anchoring support system mentioned above. These systems will cover a 300-foot span and hold about 24 inches of light snow before failure. Removable net or breakaway systems are required for heavy snow loads.

The mesh size is always a contentiously debated item. Grebes, for example, will walk on the netting and try to get through any opening large enough to fit their head through. They will get their heads stuck in 1 inch mesh and sometimes their feet in 1-1/2 inch mesh. The standard mesh opening is 1-5/8 inch in snow country with grebes. If regulations require 1 inch mesh, an emergency removal system should be designed. Quarterly maintenance is the key to long net/support system life, regardless of the quality of the netting system installed.

Bird Balls™

Bird Balls™ are a hollow plastic ball that floats on any liquid surface. The balls, for the most part, are made out of black-colored HDPE. The most common and durable is the blow-molded ball. The size of the balls range from 10 mm to 150 mm., but the most frequently used ball for outdoor use in large ponding basins is the 100 mm (4 inch), 40 gram ball. Tests have been run with balls of different diameters and weights to determine the best ball to use in high wind conditions.

The first successful use of these balls in the mining industry was undertaken in 1993 by Barrick Goldstrike in North Central Nevada. Barrick owns and operates the Goldstrike Mine which is a gold mining and ore processing facility. Euro-Matic, with whom Barrick worked, is the largest manufacturer of hollow plastic balls in the world. They are located in London and have been manufacturing hollow plastic balls for many different industrial applications.

Why do the balls keep the birds out of a large ponding basin? The assumption is that the balls camouflage the liquid surface and/or that birds attempting to land realize the improbability of a smooth landing and simply move on. This does not mean to say that birds have not landed on the balls or attempts have not been made. It is just that over the past five years there has not been verification of anything except that no birds have been seen floating amongst a million or more bird balls on some of the larger ponding basins.

What about the cost comparison of netting vs. Bird Balls™? The cost of balls will vary, depending on the quantity and shipping destination. In general, the cost comparison between netting and balls is determined by the life of the operation. It is usually cheaper to use netting and maintain the support system for a three-year project. Bird Balls™ begin to pay for themselves in a project that will operate for over three years.

It seems that the overriding factor in favor of using Bird Balls™ is zero maintenance and the ease with which the balls can be used. For example, the balls form a blanket or cover over the liquid surface, but still allow free access. When sufficient balls are poured onto a liquid they automatically arrange themselves in a blanket over the entire surface, giving a physical cover of 91% of the area when using the 100 mm (4-inch) diameter ball. The good news is that this blanket of balls is not an impediment to equipment that needs to be brought out of or placed into the basin. Balls are simply pushed aside but quickly resume the cover as the equipment moves through the liquid.

In the case of tanks, regardless of the shape, the balls always provide a constant cover. If the liquid level is reduced in a tank or basin causing the surface area to shrink, the balls simply stack in a double layer. When the liquid rises, expanding its surface area, the balls automatically spread out again into a single layer.

Another benefit that Bird Balls™ provide is the reduction in the evaporation rate. This is important at some sites, but other operations need to increase evaporation. One of the more recent thoughts has been to float PVC pipe with irrigation sprinklers in and among the Bird Balls™. The increase in surface area provided by the spherical balls should go a long way toward increased evaporation. Because the balls are black and hollow, the surface temperature of the balls will augment an increased evaporation rate. The balls also will help maintain the operating temperature of the liquid.

One of the most rigorous tests of Bird Balls™ was conducted by Bear Track Mine near Salmon, Idaho. During the first winter of operation the balls were covered with several feet of snow, with occasional ice sheets breaking away from the side slope, mounding the balls up into a heap and then freezing at night once again. During the day, as the large mounds of ice and snow partially melted, the balls would move into any exposed area created by the melting ice. The balls and liquid surface would freeze once again at night and the process began over again the next day. The result was that the balls continued to keep pace in covering any area exposed by melting ice and snow.

Table 2. Bird Ball™ Material Selection and Chemical Resistance

Specifications			
Diameter (mm)	Average Weight (g)	Number per ft^2	Number per m^2
10	0.2	1076	11,600
20	1.0	270	2,900
25	1.5	172	1,850
38	4.5	74	800
45	7.0	53	570
50	8.0	43	465
70	16.0	22	235
100	40.0	10	116

Polypropylene (PP)—Able to withstand continuous working temperatures of 230°F (110°C) and suitable for contact with most chemicals used in the metal treatment industry.

High Density Polyethylene (HDPE)—Suitable for working conditions up to 176°F (80°C). HDPE is recommended for external applications due to its enhanced resistance to freezing conditions. Black, Ultra Violet stabilizing additives prevent the degrading effects of sunlight.

PVDF—This material offers significant increase in operating temperatures up to 320°F (160°C), providing resistance to many aggressive chemicals where alternative plastics would fail.

Table 3. Evaporation test results by covering an open tank.[1]

		Hourly Heat Consumption	Evaporation Rate Per Hour
Open Tank	10.73 kW/h	13.00 lt/m^2	24.00 lbs/yds^2
With One Layer Balls	2.7 kW/h	1.67 lt/m^2	3.10 lbs/yds^2
With Two Layer Balls	2.04 kW/h	1.28 lt/m^2	2.35 lbs/yds^2
One Layer Saves	75% heat	87.2% liquid	
Two Layers Save	81% heat	90.1% liquid	

Calculate the results from above test on a continuous yearly base, 8,700 hours.

With one layer of Euro-Matic Balls: Saving of heat for 1.1m^2 (12 $feet^2$). Yearly 70,000 kW/h. Saving of liquid 99.000 liters per m^2 per year.

With two layers of Euro-Matic Balls: Saving of heat for 1.1m^2 (12 $feet^2$). Yearly 83,000 kW/h. Saving of liquid 102.000 liters per m^2 per year.

[1]Ball Size: 38 mm (1-1/2 in.)
Tank Size: 1.85 x 0.6 m (1.1 m^2)
6 ft x 2 ft (12 ft^2)
Temperature: 90°C (194°F)

Test carried out by Technological Institute, Copenhagen, Denmark. Ask for report.

CONCLUSION

From the simple beginnings of using rock music to flashing lights, and flags to stretch wire, a black box type of ultrasonic sound device, colored dye and detox processes, it became apparent that the only practical solution to keeping birds off of a ponding basin is some means of exclusion. Netting works, but it requires vigilant maintenance. The use of Bird Balls™ seems to be the answer for the long term project.

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RESEARCH AND MANAGEMENT OF BIRD DEPREDATIONS AT CATFISH FARMS

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ABSTRACT: Depredations by fish-eating birds are a major constraint on production at commercial catfish facilities in the southeastern United States. A recent survey of catfish farmers estimated total losses due to direct predation by birds and costs associated with employing preventive measures at $17 million, or 4% of national sales. In 1988, the U.S. Department of Agriculture's (USDA) National Wildlife Research Center (NWRC) established a research station in Mississippi to develop more effective methods for reducing the impact of birds on southeastern aquaculture farms. This paper describes the impact of double-crested cormorants (*Phalacrocorax auritus*, DCCO) on the catfish industry, describes control methods to reduce depredations by this species, and reviews some research currently being conducted at the NWRC Mississippi research station.

KEY WORDS: aquaculture, *Ardea herodias*, *Ictalurus punctatus*, *Phalacrocorax auritus*, *Pelecanus erythrorhynchos*, wildlife damage management

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INTRODUCTION

Commercial aquaculture in the southeastern United States encompasses a variety of industries that sustain depredations from a broad diversity of piscivorous birds. Crawfish farmers in Louisiana, tropical fish farmers in Florida, bait fish farmers in Arkansas, and catfish farmers in Mississippi, Arkansas, Alabama, and Louisiana employ different techniques to raise their products, but all sustain serious losses due to birds (Martin 1985; Hoy et al. 1989; Ross 1994; Glahn and Brugger 1995; Glahn et al. 1995). In response to this problem, in 1988 the NWRC of the USDA established a research station in Mississippi to conduct research to develop more effective methods for reducing the impact of birds on southeastern aquaculture farms. This paper describes the impact of a major avian pest species on the largest U.S. aquaculture industry, describes control methods to reduce depredations, and reviews research currently being conducted with this species at the NWRC Mississippi research station.

CATFISH FARMING

Most research at the NWRC Mississippi field station has been directed towards catfish farming, by far the largest aquaculture industry in the U.S. Commercial catfish farms produced almost 450 million pounds of catfish in 1995, accounting for 73% of all aquaculture production in the United States (The Catfish Institute 1995, Figure 1). Four states, Mississippi, Arkansas, Alabama, and Louisiana, last year accounted for 94% of commercial catfish acreage and 97% of farm sales in the United States (The Catfish Institute 1995). Mississippi alone accounted for 54% of the acreage and 71% of farm sales of catfish in the U.S. (Table 1).

Most catfish farms in Mississippi are concentrated along the flood plain of the Mississippi River in the northwestern portion of the state, a region commonly referred to as the Mississippi delta. More than 40,000 ha (100,000 acres) in Mississippi are devoted to catfish production.

A typical Mississippi catfish farm contains a complex of ponds, each encompassing about 6.5 to 8 ha (16 to 20 ac) of water 1 to 2 m (3 to 6 ft) deep and supporting 5,000 to 150,000 fish per hectare. Such high concentrations of fish are an irresistible attraction to birds.

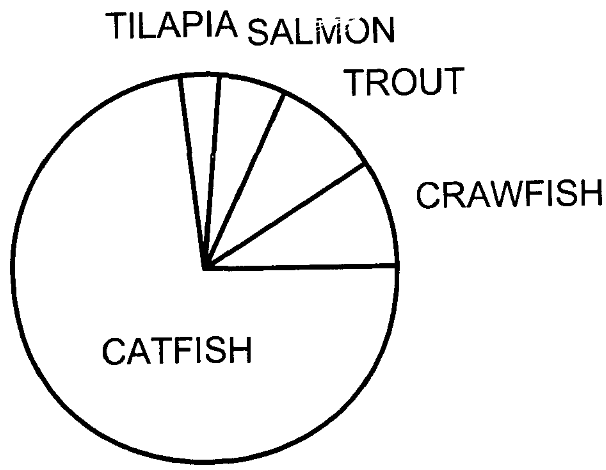

Figure 1. Percent sales of five major components of U.S. aquaculture in 1995. Total sales for all components was $552 million.

Table 1. U.S. catfish production, 1997.

State	Hectares	Sales (x1,000)
Mississippi	41,279	$275,559
Arkansas	11,534	52,214
Alabama	8,499	45,126
Louisiana	5,787	27,273
Other	4,678	17,606

BIRD DEPREDATIONS

In a recent survey (U.S. Dept. of Agric. 1997), catfish farmers identified wildlife as their second leading cause of losses. The vast majority of farmers indicated that birds, particularly cormorants and herons, were their biggest wildlife concern.

Wading birds such as great blue herons (*Ardea herodias*, GTBH) and great egrets (*Ardea alba*, GREG) are ubiquitous on catfish farms throughout most of the year. For the past two years, James Glahn, a wildlife research biologist at the NWRC Mississippi research station, has been conducting both field and pen studies to determine the foraging habits, diet, and impact of GTBH on catfish farms. The results will indicate when and where GTBH are likely to have the biggest impact on production and should help aquaculturists determine thresholds for applying damage control measures for these species.

American white pelicans (*Pelecanus erythrorhynchos*, AWPE) are an increasing concern to catfish farmers (King 1997). Flocks of 1,500 to 2,000 birds are common on catfish farms and adjacent flooded fields in the Mississippi delta. The large size and greater food requirements of this species, together with a propensity to forage at night, make pelicans a potentially large threat to catfish producers (Mott and Brunson 1997). Tommy King, another wildlife research biologist at the NWRC research station, has been monitoring pelican populations, movements, and daily activity budgets for the past several years in an attempt to clarify the impact of this species.

The most significant avian predator on catfish farms is the DCCO, a diving, fish-eating bird whose range extends across North America. DCCO populations have increased dramatically over much of North America during the past two decades, due mainly to a ban in 1972 on the use of DDT, reduced persecution on the breeding grounds, and possibly increased prey abundance on both their breeding and wintering grounds (Weseloh et al. 1995; Jackson and Jackson 1995). More than 350,000 pairs of DCCO currently breed in North America, with a total population probably between 1 and 2 million birds (Belant and Tyson 1997).

The biggest increases have come with interior populations that breed on the Great Lakes and in the Canadian prairie provinces and north-central U.S. (Belant and Tyson 1997). Every fall, several hundred thousand DCCO migrate south through the Mississippi Valley (Dolbeer 1991). In recent historical times, most of these birds spent the winter along the gulf coast. However, with the rise of the catfish industry, an increasing number of DCCO stop off farther north in Louisiana, Arkansas, and Mississippi.

DCCO populations increased dramatically during the 1980s along with the rapid rise of commercial catfish aquaculture in the Mississippi delta (Glahn and Stickley 1995). Since 1990, NWRC biologists and USDA Wildlife Services operations personnel have documented the continued increase in DCCO populations by monitoring active roost sites in the delta (Aderman and Hill 1995; Glahn et al. 1996). Numbers have increased from about 27,000 DCCO in 1990 to >68,000 birds in 1998 (Figure 2). Cormorant populations typically increase in the delta between November and January, reach a peak in February, and decline during the latter part of March as birds migrate north to breed (Glahn et al. 1996).

Jim Glahn and Kristin Brugger (1995) analyzed estimated DCCO population size, feeding rates, and prey size to construct a DCCO bioenergetics model. Their results indicated that DCCO in the Mississippi delta consume about $2 million worth of catfish, or about 4% of the potential harvest, annually.

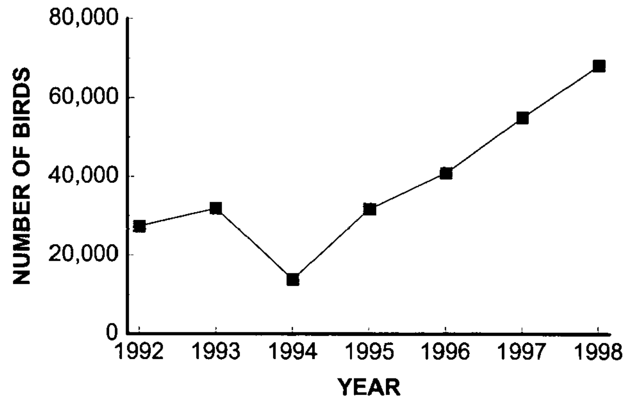

Figure 2. Number of double-crested cormorants censused at night roosts in the delta region of Mississippi during one night in January of each year. U.S. Department of Agriculture, Wildlife Services biologists identified all active roosts in the delta, and counted the number of cormorants flying into each roost in the evening or flying out the next morning.

DAMAGE CONTROL MEASURES

Eighty-seven percent of 281 Mississippi catfish farmers who responded to a survey in 1988 felt that fish-eating birds were enough of problem to warrant applying some control measures (Stickley and Andrews 1989). These growers spent an average of $7,400 to control bird depredations on their farms, amounting to estimated delta-wide expenditures of about $2 million. In spite of these efforts, growers still may have lost >$3 million because of birds.

A more recent survey (Wywialowsky 1998) estimated that in 1996 catfish producers lost $11.5 million due to bird predation. Estimated total losses due to direct predation and costs associated with employing preventive measures amounted to $17 million, or 4% of national catfish sales.

Management of DCCO depredations on catfish farms consists of trying to repel birds from farms, reducing local populations, and dispersing birds from night roosts near catfish farms (Mott and Boyd 1995). NWRC biologists have evaluated several techniques for repelling DCCO from catfish ponds, including floating ropes to interfere with DCCO landing and taking off from ponds (Mott et al. 1995) and a human effigy called "scary man" that inflates and makes loud noises (Stickley and King 1995; Stickley et al. 1995). Both techniques deterred birds for a limited time, but eventually birds habituated to them. The expense of employing these measures would probably limit their use.

For most farmers, scaring birds consists of patrolling levees and shooting pyrotechnics or shotgun shells. Of course shooting a shotgun can be both a scaring and a lethal technique. Aquaculture farmers in the Southeast can apply for depredation permits to shoot birds on their farms. In 1995, farmers reported taking 7,756 DCCO, 2,798 GTBH, 1,975 GREG, and 1,448 birds of other species under 904 permits issued by the U.S. Fish and Wildlife Service (USFWS) (Belant et al. 1998). The vast majority of these birds were taken in the states of Arkansas, Mississippi, and to a lesser extent, Louisiana.

Interestingly, actual numbers of birds reported taken under aquaculture depredation permits was only 62% of that authorized (Belant et al. 1998). Birds quickly become wary and increasingly difficult to shoot, and patrollers often cannot get within shooting range of birds. The main value of shooting probably is not so much to reduce regional populations, but to reinforce scaring efforts. Belant et al. (1998) recently concluded that birds taken under depredation permits between 1987 and 1995 had no effect either on regional winter populations or on continental breeding populations.

The USFWS recently issued a standing depredation order (63 FR 10550) that allows aquaculture farmers in 13 states, mostly in the Southeast, to shoot DCCO without a permit if the birds are causing or are about to cause damage on their farms. The USFWS does not anticipate any significant increase in take, but the new regulations will eliminate much paperwork both for farmers and the USFWS.

The third component of DCCO management consists of dispersing birds from night roosts near aquaculture farms (Mott et al. 1992, in press). DCCO typically roost in emergent bald cypress/tupelo gum trees in congregations of from several hundred to 10,000 or more birds. More than 60 DCCO roost sites have been identified in the Mississippi delta of which 10 to 15 typically are used during any given night. Many roosts are concentrated in the southeastern portion of the delta, near the main concentration of catfish farms.

Teams of farmers harass birds by shooting guns, bird bombs, screamers, and other non-lethal noise-making devices as birds fly into roosts for the night. Birds usually abandon the site after 1 to 3 nights of such harassment.

The development of the DCCO roost dispersal program in the Mississippi delta has been a cooperative effort among the NWRC Mississippi research station, the USDA/WS operational program, and the catfish farmers themselves. Don Mott and his coworkers (Mott et al. 1992, in press) demonstrated that 1 to 3 nights of widespread, consistent, and coordinated harassment could cause birds to abandon roost sites near catfish farms in the eastern part of the Delta and move to roosts along the Mississippi River. Furthermore, they documented that such efforts resulted in reduced DCCO populations at nearby catfish farms. The program subsequently was taken over by catfish farmers themselves, with significant logistic and technical assistance from WS operations personnel. The latter monitored roost sites and mobilized manpower to disperse birds when and where necessary. Coordinating such an effort over the entire delta logistically is a monumental task.

Biologists from the NWRC Mississippi research station continue to monitor the effectiveness of the roost dispersal program. Last winter 50 DCCO were captured and outfitted with transmitters to determine the effect of roost harassment on roosting and foraging behavior. To monitor roosting locations, two people rode in separate vehicles along two transects at night and used scanning receivers to detect any radio-tagged birds at major potential roosting locations. Seventy-eight percent, 59%, 53%, and 32%, respectively, of cormorants identified at any particular roost returned to that same roost 1 night, 2 nights, 3 to 5 nights, or >6 nights later, indicating that DCCO tend to return to the same night roost site on succeeding nights. The above results are for all birds, regardless of whether they were harassed. Roost fidelity would have been even stronger if movements of harassed and non-harassed birds had been analyzed.

Roost fidelity of birds from harassed versus and non-harassed roosts were compared with regard to whether they returned to the same site within 48 hours. Eighty-one percent of birds returned to the same site when not harassed, compared to only 11% for harassed birds. When they did change night roosts, harassed birds also traveled farther (median distance = 26 km) than non-harassed birds (median distance = 0 km). Clearly birds tended to change roost locations more often and travel farther when they were harassed.

A main objective of the roost dispersal study program is to move birds to roosts along the Mississippi River and away from the major concentration of catfish farms. Glahn et al. (1995) identified stomach contents of DCCO collected in the MS delta and found that catfish made up about 75% of the diet of birds collected in the interior delta, but only about 14% of the diet of birds collected along the Mississippi River. One of the major things to be determined by the study is whether birds that roosted along the river are likely to return to the eastern delta the next day to feed. Foraging activity was monitored by flying over the delta during the day to locate telemetered birds. Only 7% of telemetered DCCO that roosted along the river foraged in the eastern delta the next day, compared to 100% of birds that roosted in the interior delta.

SUMMARY

Depredations by GTBH, AWPE, and DCCO are a major concern of aquaculturists in the southeastern U.S. Management of bird depredations on catfish farms entails repelling birds from farms, reducing local populations, and dispersing birds from night roosts in major catfish-growing areas. Farmers patrol their facilities regularly throughout the winter and use both frightening devices and lethal means to reduce depredations on their farms. Lethal control is important not only for reducing local populations on particular farms, but also for reinforcing non-lethal scaring techniques. Relocating cormorant roosts away from areas of concentrated aquaculture production is an important non-lethal component of an integrated program to reduce the very real and substantial impact that DCCO have on the catfish industry in Mississippi. Clearly, relocating roosting DCCO from the interior delta to the Mississippi River is an effective strategy for reducing depredations at catfish farms.

ACKNOWLEDGMENTS
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STRATEGIES FOR ALLEVIATING VULTURE DAMAGE IN INDUSTRIAL PLANTS

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ABSTRACT: Since 1985, USDA-APHIS-Wildlife Services (WS) personnel have received complaints concerning black vultures (*Coragyps atratus*) and turkey vultures (*Cathartes aura*) roosting at industrial facilities along the Texas gulf coast. The structures associated with these facilities are difficult for bird control personnel to access, and remote vulture roosting sites limit the effectiveness of many commonly used bird damage control methods. Methods attempted since 1985 include: capture and relocation, exclusion, harassment and shooting. In 1994, WS entered into a cooperative vulture control agreement with three chemical plants located in southeast Texas. WS personnel have developed an effective vulture damage management strategy that is currently used at six industrial sites in Texas.

KEY WORDS: *Coragyps atratus*, *Cathartes aura*, roosting, disperse, trapping, tagging, relocation, shooting, exclusion, harassment, structure

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INTRODUCTION

The Texas Gulf Coast is home to numerous petrochemical refineries and industrial facilities. Vertebrate pest species cause extensive damage to these facilities and create human health and safety hazards. Vulture damage complaints at industrial facilities have increased in Texas.

In 1994, three chemical plants in southeast Texas contacted Wildlife Services (WS) and requested assistance with vulture damage control. The chemical plants reported extensive damage to structures and threats to human safety caused by black vultures (*Coragyps atratus*) and turkey vultures (*Cathartes aura*). Diseases and unsafe work areas associated with the accumulation of bird droppings concerned plant administrators responsible for employee health and safety standards. Vulture damage at the southeast Texas chemical plants was estimated at $450,000 for the period January 1994 through December 1997 (Anonymous 1997). Damage was related to clean-up, structure repair and other maintenance associated with the accumulation of droppings and feathers. Human health and safety concerns were related to the accumulation of droppings on walkways, stairs, handrails and other work areas. Several plant employees were hit by vulture droppings while working on plant structures.

The area supports a large population of resident and migratory vultures. Seasonal variations in the numbers of birds observed at each plant site have been reported by WS and plant personnel. WS personnel estimate that migrant birds increase the area's non-migrant winter vulture population by 300%. Estimated daily averages of 200 birds per plant site were reported by WS personnel when control work began in January 1994. Vultures are attracted to industrial facilities for several reasons. These sites offer an abundance of roosting and perching locations and the vultures are able to soar on thermals created by industrial operations. During cold weather industrial facilities also offer warm, sheltered areas for vultures to perch. The majority of the vultures have been observed congregating at the plants at sundown and leaving the roosting sites by mid-morning. Few vultures have been observed at the plant sites during mid-day hours.

DAMAGE SITES AND METHODS

The plant sites are located on coastal prairie within the Gulf Prairies and Marsh area of Texas. Climax vegetation is largely tall grass prairie, however, much of the area has been invaded by trees and brush such as mesquite (*Prosopis glandulosa*), oaks (*Quercus* spp.) and pricklypear (*Opuntia* spp.). Major agricultural operations include raising cotton, sorghum, corn and cattle.

The production unit areas at the three plants varied in size. Plant #3 production operations covered the largest area and had the largest number of structures, while plant #2 covered the smallest area and had the smallest number of structures (Table 1). Prior to 1994, plant personnel were primarily responsible for exclusion and harassment efforts, while WS personnel conducted other control work involving shooting and harassing.

Pyrotechnics, Mylar® tape and human effigies have been used to harass vultures at the plant sites. Screamers and cracker shells launched from pistols and shotguns respectively, have been used to deter birds from roosts and perches on plant structures. These techniques have been used exclusively, by plant personnel.

Exclusion techniques used were: netting and porcupine wire (Nixalite®). Plant managers at plants #1 and #3 used netting and porcupine wire in attempts to exclude vultures from roosting areas. Netting was draped over roosting areas and porcupine wire was placed on surfaces commonly used by vultures.

Beginning August 8, 1994, WS personnel captured, tagged and relocated vultures in efforts to reduce vulture damage at plant sites. Tagging and relocation was done under a federal bird banding permit. Vultures were tagged to determine if relocated birds would return to the plant sites. Live traps were placed at several locations on each plant site. The traps were baited with carrion, and decoy birds were used to increase trap effectiveness. Traps were shaded and equipped with water containers.

Vultures were tagged on the right wing with a colored tag and numbered livestock tag. The colored tag served

Table 1. Description of Plants

Table 1. Description of Plants

Plant Site	Unit Area	Number of Columns	Average Column Height	Average Distance Between Columns
1	6 ha	10	70 m	100 m
2	1 ha	3	60 m	50 m
3	8 ha	15	90 m	50 m

to identify the birds from long distances, while the numbered tag provided specific information, including capture site, capture date, release site, and tag applicator. The tags were placed on the patagium of the right wing (Coleman et al. 1985). Three tag colors were used to distinguish plant sites. Tag colors were applied as follows: blue (plant #1), pink (plant #2), yellow (plant #3).

Vultures were transported in a kennel-type trailer that provided sufficient ventilation and shading. Ventilation was important during the spring and summer months, in order to reduce stress associated with heat. After receiving park and refuge manager's approval, vultures were released at State Parks and National Wildlife Refuges in central and southeast Texas. Distances between release and capture sites averaged 190 km.

Beginning December 1, 1994, the manager at plant #2 agreed to allow WS personnel to use shooting and pyrotechnics as a control method. The manager for plant #3 agreed to allow shooting and pyrotechnics beginning February 19, 1996, and the plant #1 manager agreed December 1, 1996. Air rifles (.22 cal.) and rimfire rifles (.22 cal.) with scopes were used to shoot birds roosting or perching on remote structures. Shooting was used as a positive reinforcement of pyrotechnics. Frequently, birds were roosting in remote locations and personnel shot from catwalks, ladders and platforms to minimize shooting distances.

RESULTS

Mylar® tape and human effigies used by plant personnel to deter vultures from plant structures were ineffective. Pyrotechnics, when used exclusively, were also ineffective because vultures quickly became conditioned and could not be deterred from remote structures. Distances between structures and the total area of each plant site were factors that influenced the effectiveness of harassment. The greater the distance between the structures, the more difficult it was to remove the birds from the area because the vultures simply moved from one end of the plant site to the other. Structure height also influenced the success of the harassment methods; the higher the structure the more difficult the vultures were to remove.

Attempts to exclude vultures from plant structures have not reduced damage or vulture numbers. Netting and porcupine wire excluded vultures from some areas, but they quickly relocated to areas where the materials could not be used due to safety considerations or installation problems.

WS personnel live trapped 3,027 vultures between August 8, 1994 and May 15, 1996. Trapping results and associated mortality are reported in Table 2. The results indicate that live trapping is an effective capture method. However, trapping had little effect on the numbers of vultures that continued to roost at plant sites. WS personnel did not observe trapping related decreases in vulture numbers at plant sites; observed decreases were the result of seasonal changes.

Flock composition varied between plant sites. Ninety-five percent of the vultures captured at plant #1 and plant #2 were black vultures. Five percent of the vultures captured at these two plants were turkey vultures, as compared to 51% black vultures and 49% turkey vultures captured at plant #3. It is possible that black vultures were more attracted to the habitat surrounding plant sites #1 and #2. This habitat held higher numbers of white-tailed deer (*Odocoileus virginianus*) and cattle. Black vultures are attracted to large carrion; according to Paterson (1984), larger carcasses are preferred by the more gregarious black vultures and smaller carcasses are preferred by turkey vultures. Plant site #3 was primarily surrounded by farmland.

Since December 1, 1994, shooting has been the primary control method at plant #2. On day 3, after shooting began, all vultures abandoned the plant site and did not return for four months. Twenty-five vultures were shot during the three day period. The vultures were shot with a .22 cal. rifle. Since the initial shooting project at plant #2, WS personnel have worked a yearly average of six days during the fall and winter months to move vultures from the site. A total of 49 vultures have been removed from plant #2 since completion of the initial shooting effort.

Shooting began at plant #3 on February 18, 1996. After four days of shooting, vultures abandoned the site for 12 months. Five vultures were shot during the four day period. Vultures returned to plant #3 in February 1997, and after three days of shooting the vultures deserted the site. No vultures were taken during these three days. Since February 1997, no vultures have returned to plant #3.

Shooting began at plant #1 on March 24, 1997. After 14 days of shooting, vultures abandoned the site and did not return for 10 weeks. Forty-five vultures were shot during the 14 day period. The vultures were shot with a .22 cal. air rifle. Since the initial shooting effort, 27 vultures have been removed.

Table 2. Number of vultures captured at plant sites, August 1994 to May 1996.

Vultures Captured	Plant #1	Plant #2	Plant #3	Total
Total tagged vultures	554	1546	487	2587
Total black vultures	536	1494	247	2277
Total turkey vultures	18	52	240	310
Recaptured black vultures	10	61	13	84
Recaptured turkey vultures	1	0	21	22
Associated Mortality	104	133	87	324

CONCLUSION

Commonly used bird control methods such as exclusion and harassment had limited application for vulture control at these industrial facilities. Maintenance requirements, safety concerns and inaccessible roosting areas can limit the use and effectiveness of the control methods. Vultures were easily captured in live traps; however, capture and relocation did not reduce vulture numbers or reduce damage at the plant sites. In central and southeast Texas, where vultures were relocated, complaints concerning vulture damage increased. WS personnel received several calls from individuals who complained about damage caused by released vultures. Refuge and State Park managers refused to accept additional birds after large numbers of vultures began to congregate at recreation areas. One State Park manager requested assistance with vulture damage control after vultures were released at the park.

The .22 cal. rimfire rifle increased the effective shooting range and performed better under adverse conditions (high wind, rain). A .22 cal. air rifle has been used in situations where there was a potential risk of igniting flammable products or damaging equipment. The presence of plant personnel in some areas also dictated the use of the .22 cal. air rifle. The author's efforts and observations suggest that shooting used in conjunction with pyrotechnics may be the most effective control strategy for reducing vulture damage at some industrial sites.

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THE USE OF AEROSOL REPELLENTS AS AN AVIAN DETERRENT STRATEGY

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ABSTRACT: Traditional protective measures to keep wildlife away from areas include exclusion by use of netting, hazing, and chemical repellents. The primary problem with most hazing systems is that wildlife quickly habituate to the devices if their use falls into a predictable pattern. Repellent substances cause wildlife species to avoid otherwise attractive or palatable resources by creating a disincentive to visit a specific area or consume a particular resource. Chemical repellents, both lethal and non-lethal, are typically used for agricultural and horticultural purposes, but in addition may provide a strategy to deter wildlife in other contexts. Aerosol delivery of chemical repellents might work to effectively target birds in the air prior to landing in a hazardous area (i.e., a toxic waste water impoundment). In theory, aerosol delivery of a known avian irritant could be used as an ancillary tool in bird hazing systems, to complement more traditional auditory and visual scare tactics.

KEY WORDS: aerosol, repellents, hazing, trigeminal irritants, methyl anthranilate

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Traditional protective measures to keep wildlife away from areas include exclusion by use of netting, hazing, and chemical repellents (Jackson 1990; Hyngstrom et al. 1994). However, exclusionary netting or fencing may not be economically or logistically feasible when large areas need to be protected. Additionally, fencing tends to restrict access for most terrestrial vertebrate species, but does little to prevent birds from utilizing the resource. Common hazing techniques rely on auditory and visual devices to repel birds from an area, e.g., bird distress calls, pyrotechnics, propane cannons, flashing lights, effigies of humans or predators, and flagging (Allen 1990; Jackson 1990; Denver Knight Piesold 1992). These techniques are usually presented on a static (i.e., continuous) or timed interval schedule. The primary problem with most hazing systems is that wildlife quickly habituate to the devices if their use falls into a predictable pattern (Allen 1990). In terms of an operant conditioning paradigm, habituation is defined as the extinction of a behavioral response (i.e., an avoidance response) due to the lack of a salient reinforcing stimulus (Lehner 1996). For example, numerous techniques were employed at the Paradise Peak Gold Mine to prevent bird use of the cyanide leachate ponds, but within a few days birds were observed perching on, or swimming around, the 6,000 watt loudspeakers and propane cannons (Allen 1990). Thus, habituation can account in large part for the failure of most traditional hazing systems.

Repellent substances cause wildlife species to avoid otherwise attractive or palatable resources by creating a disincentive to visit a specific area or consume a particular resource (Rogers 1980; Harborne 1982). Chemical repellents, both lethal and non-lethal, are typically used for agricultural and horticultural purposes, but in addition may provide a strategy to deter wildlife in other contexts. Primary chemical repellents tend to promote avoidance upon first exposure, whereas secondary repellents require learning to associate post-ingestional sickness with consumption of the repellent agent (Rogers 1980). Secondary repellents are less desirable in situations where ingestion of a resource carries a high risk of mortality, i.e., in agricultural contexts where toxic granular pesticides may be mistaken by birds for food or grit. Most chemical compounds used in wildlife management are derived from natural plant products. Plants have responded to animal depredation by incorporating repellent or toxic chemicals into their tissues that target animal chemosensory systems, thereby eliciting chemosensory irritation as a defense mechanism (Harborne 1982). Chemosensory irritation is mediated via stimulation of the trigeminal nerve, the principle somatosensory nerve of the head that codes for mechanical, thermal, and chemically noxious stimuli. A familiar example is the transient burning sensation experienced when ingesting capsaicin, the active ingredient in chili peppers. Interestingly, this compound only affects mammals, while avian seed dispersers are insensitive to capsaicin's effect (Szolcsanyi 1986; Clark 1998). Birds are sensitive to other naturally-derived compounds, however (Mason et al. 1992; Shah et al. 1992). Methyl anthranilate (MA), the principle ingredient of grape flavoring, has been shown to be a potent avian irritant (Kare 1961). MA has been successfully used as a non-lethal repellent in laboratory feeding (Glahn et al. 1989; Mason et al. 1989; Cummings et al. 1992; Avery et al. 1995) and drinking trials (Dolbeer et al. 1992; Clark and Shah 1993; Belant et al. 1995; Clark 1996), and as a topical application to turf grass (Cummings et al. 1995), landfills, and standing water at airports (Dolbeer et al. 1993) to minimize the extent of bird-associated damage.

Waste water impoundments resulting from industrial operations can be a significant contributory risk factor for morbidity and mortality of migratory birds (Kay 1990; Denver Knight Piesold 1992). The risk is increased when these sites occur in arid areas where potable water is generally less available. For example, impoundments located in deserts can attract migrating waterfowl to areas not previously documented to be migratory flyways (Allen 1990). Artificial waste containment ponds such as those affiliated with gold mining activities can be acutely lethal to birds upon contact or ingestion, or may generally reduce health due to bioaccumulation of toxic substances (Clark and Shah 1991). In these situations, incorporating topical applications of chemical repellents (i.e., to the pond surface) would still allow waterfowl contact with hazardous materials, and would most likely not achieve the goal of zero mortality established by regulatory requirements. For this reason, chemical repellents have not previously been used as a protective tactic in industrial waste water settings.

Aerosol delivery of chemical repellents, however, might address this shortcoming, and work to effectively target birds in the air prior to landing. The nociceptive system that mediates the detection of orally presented irritants also innervates the mucosae of the nose and eyes. The principle behind the use of avian aerosol repellents, therefore, is the same as that exploited in the use of CS and CN tear gases for human crowd control (Yih 1995; Anderson et al. 1996). Aerosol delivery strategies have also been used in agricultural contexts to effectively disseminate insect pheromones in communication-disruption programs. It was found that "puffer cans" (aerosol-releasing devices) provided an efficient means to target insect pheromone receptors under field conditions (Shorey et al. 1996). In order to determine the efficacy of such a deterrent strategy for birds and the nature of the behavioral response to aerosols, laboratory trials were conducted in which European starlings (*Sturnus vulgaris*) were exposed to short (30 second) aerosol bursts of methyl anthranilate (Stevens and Clark in prep., a). Results illustrate that birds demonstrate a clear irritation response to MA aerosols, with no evidence of habituation (i.e., reduced responsiveness) under repeated exposures.

In theory, aerosol delivery of a known avian irritant could be used as an ancillary tool in bird hazing systems to complement more traditional auditory and visual scare tactics. Sensory irritation caused by contact with MA aerosols would be the aversive reinforcing stimulus that attaches a tangible consequence—a punishment—to the visual and auditory stimuli (Lehner 1996). The integration of such a chemical irritant could thus boost the efficacy of the system as a whole by increasing the salience of these other stimuli and minimizing habituation.

In the field, aerosol delivery strategies must take into account factors affecting aerosol plume behavior. Standard plume monitoring involves measurements of windspeed and direction, the amount of effluent released, the source height, and initial velocity of the plume (Neiburger 1973). For large-scale plume releases, e.g., industrial smokestacks, knowledge of weather conditions and local topography also contributes to monitoring efforts (Briggs 1969). For the relatively small scale on which aerosol hazing devices would operate, the most important factor to measure is aerosol droplet density as a function of source height, downwind distance, and windspeed. If birds' threshold sensitivity to the repellent is also known (i.e., from laboratory studies on concentration-response relationships), droplet density measurements in the field can significantly aid in predicting whether or not incoming birds will respond to aerosol plume exposure.

Software packages that model aerosol plume behavior have been developed for use in the industrial sector to aid in site selection of hazardous materials or to predict downwind effluent concentrations. Clark and Shah (1992) have applied this technology to predict olfactory-mediated foraging behavior in Leach's storm petrels (*Oceanodroma leucophrys*). Application of aerosol plume models to the planning of bird hazing operations will allow system managers to optimize placement of aerosol sprayers in order to maximize the likelihood of targeting birds in flight with an effective dose. Computer simulations of plume behavior must incorporate data on prevailing wind conditions, bird flight patterns over the protected area, estimates of aerosol sprayer coverage, and avian detection thresholds (Stevens and Clark in prep., b). Initially this necessitates intensive field observations, but avoids inefficiencies and errors in the siting of hazing devices within the protected area.

In conclusion, results of recent laboratory and field studies indicate that incorporating aerosol delivery of a chemosensory irritant such as methyl anthranilate into a bird hazing system can minimize habituation and increase the efficacy of the system as a whole. Aerosols provide a practical and efficient solution to traditional bird hazing problems, and merit further investigation and refinement as an avian deterrent strategy.

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MAMMALIAN RESERVOIRS AND THE CHANGING EPIDEMIOLOGY OF RABIES IN THE UNITED STATES

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ABSTRACT: The epidemiology of rabies in the United States has changed dramatically over the past few decades. Greater than 90% of all animal rabies cases reported annually to the Centers for Disease Control and Prevention now occur in wildlife, whereas before 1960 the majority were domestic animals. The principal rabies reservoirs today are wild carnivores and bats, infected with many different types of rabies virus variants. Annual reporting of human deaths have fallen from more than 100 at the turn of the century to one to six per year, despite major outbreaks of animal rabies in several distinct geographic areas. Most recent human rabies cases acquired in the United States are the result of infection with rabies virus variants associated with bats, although the exact incident leading to exposure has been difficult to define. Many recent deaths have occurred in persons who failed to seek post-exposure treatment, presumably because they did not recognize a risk in the animal contact leading to the infection or failed to recognize that contact had occurred. Although these human rabies deaths are rare, estimated public health costs associated with disease detection, prevention, and control have risen, exceeding millions of dollars each year.

KEY WORDS: rabies, animal bites, raccoons, bats, skunks, vaccination, epidemiology

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INTRODUCTION

Perhaps the oldest recognized zoonotic disease, rabies continues to cause >35,000 deaths annually. These potentially preventable deaths occur primarily in Asia, Africa, and Latin America, where most of the virus transmission to humans results from bites inflicted by rabid dogs (WHO 1993). In contrast, in the United States and other developed nations, animal control and vaccination programs coupled with effective and widely available biologics for post-exposure prophylaxis (PEP), have reduced the annual number of human rabies deaths to a few per year. The epidemiology of rabies in the United States has changed radically since the era when dog rabies predominated (Held et al. 1967). Human exposures and disease are still ultimately linked to cycles of rabies virus transmission in animals, however, wildlife now make the greatest contribution to annual total rabies cases in the United States (Figure 1; Krebs et al. 1997). It is probable that the incidence of rabies in humans in the United States has approached a level that cannot be further reduced without targeting wildlife for rabies control. However, even if rabies virus was eliminated in terrestrial carnivores, human deaths would not be reduced to zero because for the last decade the majority of human cases have been associated with variants of rabies virus maintained in a chiropteran reservoir (Noah et al. 1998).

METHODS AND RESULTS

Rabies Virus and Reservoir Hosts

Rabies virus is one of six (or seven if the Pteropid bat virus from Australia receives serotype/genotype status [Speare et al. 1997]) virus serotypes/genotypes in the genus *Lyssavirus* (family Rhabdoviridae) (Bourhy et al. 1993). This family is one of three in the Order Mononegavirales, which is made up of agents with single stranded negative sense RNA genomes. Several of the lyssavirus serotypes/genotypes have been associated with neurotropic disease in humans and animals including Mokola, Duvenhage, European bat lyssavirus types I and II, and Pteropid bat virus (Meredith et al. 1971; Familusi et al. 1972; Selimov et al. 1989; Fraser et al. 1996). Rabies (serotype/genotype 1) virus has a near global distribution, with the exceptions of Antarctica and Australia.

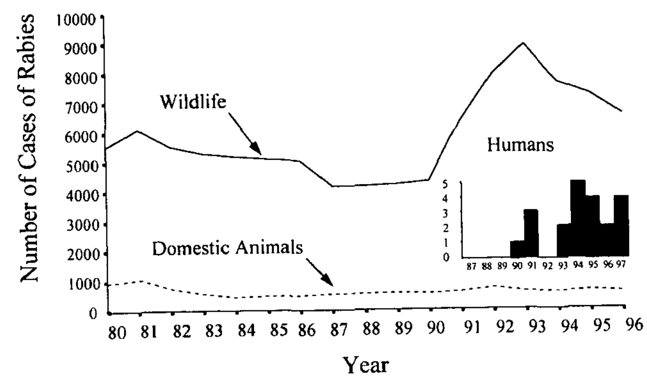

Figure 1. The trend in reported rabies cases shows wildlife to be the principal reservoir of rabies virus in the United States. The increase in reported wildlife cases during the 1990s has been primarily associated with an epizootic of rabies in raccoons in the eastern United States. The number of human rabies cases acquired within the United States has shown an apparent increase since the mid-1980s, unrelated to the increase in rabies in terrestrial carnivores.

Over the past 20 years, an understanding of epidemiologic patterns of rabies virus maintenance in natural populations has occurred through advances in immunology and molecular biology. Applications of monoclonal antibodies for antigenic typing and genetic sequence analyses of rabies virus variants have defined enzootic maintenance cycles of unique variants of rabies virus primarily associated with a single species of mammal (the reservoir host) within geographic regions in the United States (Rupprecht et al. 1987; Smith 1989; Smith and Seidel 1993). Within these defined regions, these unique variants of rabies virus can be recovered from multiple species of mammals infected by transmission from the primary reservoir host, but this "spillover" does not typically result in adaptation of the variant to additional host species and subsequent independent maintenance cycles. This association of virus and host means that the spatial distributions of rabies variants in specific mammalian carnivores have distinct geographic boundaries which can be mapped using data submitted to the Centers for Disease Control and Prevention (CDC) by state and territorial rabies laboratories (Krebs et al. 1996; Krebs et al. 1997). These data and maps provide valuable information on the distribution of endemic or epidemic rabies in animals, and over time provide a dynamic view of the how this virus spreads through and influences host populations. Overlaying the distribution of rabies viruses in terrestrial mammals are multiple, independent reservoirs for rabies virus in numerous species of insect-eating bats in the United States. At least 30, of the approximately 39 species of bats which occur in the United States, have been found to be rabid at some time (Constantine 1979). Patterns in the distributions of bat-associated rabies virus variants can be more difficult to detect as many species of bats are migratory and populations are thus intermixed (Smith 1988). This surveillance information is of tremendous importance to local and state health departments for planning annual budgets related to rabies prevention and to prepare for control measures directed at owned animals and wildlife.

The current distribution of the major variants of rabies virus and their associated terrestrial wildlife hosts cover much of the continental United States (Figure 2). Once established within a particular animal population, rabies virus transmission can persist for decades, perhaps for centuries. Rabies has been enzootic in Arctic fox (*Alopex lagopus*) and red fox (*Vulpes vulpes*) populations of Alaska and New England, respectively, and in raccoon (*Procyon lotor*) populations of the southeastern states for at least 50 years. Annual fluctuations in the numbers of rabid animals reported from specific locales are the rule, but frequently the disease persists at low levels (enzootic). Rabies virus can also cause sensational epizootics, as occurred in raccoon populations along the eastern seaboard of the United States over the last two decades (Anonymous 1997a). The outbreak was believed to have been initiated when infected raccoons originating from the established southeastern focus of rabies in raccoons were translocated to the mid-Atlantic region for hunting and trapping (Nettles et al. 1979). Since the mid-1970s, a rabies variant highly adapted to raccoons has spread from the mid-Atlantic region to Maine, and caused one of the most intensive epizootics of animal rabies ever recorded (Figure 3). The magnitude of this epizootic was enhanced by the spread of virus through naive raccoon populations of very high density, sometimes in states which had not experienced terrestrial rabies for decades (Rupprecht and Smith 1994).

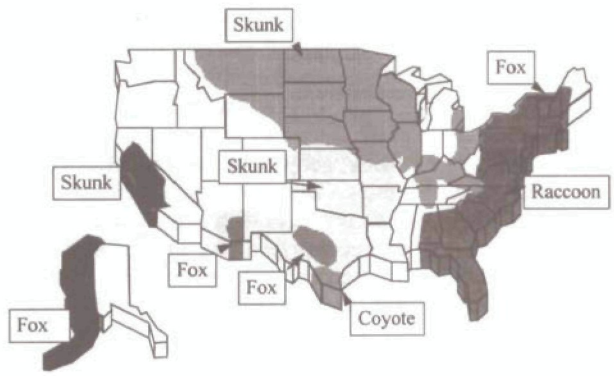

Figure 2. Distribution of the endemic areas for various rabies virus variants with their major terrestrial reservoirs in the United States.

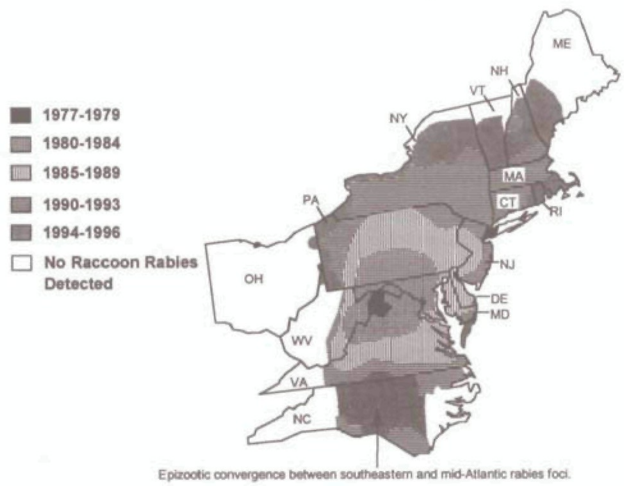

Figure 3. Expansion of the area of the eastern United States affected by the epizootic of rabies in raccoons. Rabies virus was presumably introduced into the West Virginia/Virginia region in the mid-1970s.

The natural accumulation of mutations in rabies virus that results in distinctive virus variants in spatially "isolated" carnivore populations, also occurs with rabies variants associated with bats. However, the behavior of bats complicate attempts to define neat geographical boundaries to a particular variant range. A virus variant associated with a particular bat species can be found throughout a migratory range that may extend over thousands of miles (Baer and Smith 1991). For example, rabies virus associated with Mexican free-tailed bats

(*Tadarida brasiliensis*) shows minimal sequence variation in samples collected in Florida, Alabama, Texas, New Mexico, Nevada, Colorado, and California. Similarly, samples from the migratory silver-haired bat (*Lasionycteris noctivagans*) in New York, Wisconsin, Washington, Colorado, and California are nearly identical. All areas of the United States, with the exception of Alaska and Hawaii, are home to a variety of different bat species affected by rabies. These associations result in enzootic rabies in the continental United States in several different bat species, each transmitting a distinct rabies variant.

The Epidemiology of Human Rabies

Human rabies cases diagnosed in the United States declined from 10 to 12 cases annually at the end of World War II to one to two cases per year by 1990 (Held et al. 1967; Anderson et al. 1984). Unfortunately, since 1990 this number again appears to be on the rise (Figure 1), which is presumably the result of a variety of changes in the epidemiology of this disease (Noah et al. 1998). Of primary concern in recent decades is the increasing recognition of variants of rabies virus associated with a bat reservoir as important causes of human rabies. During the period from 1990 to 1997, 19 of the 21 cases of human rabies believed to have been acquired through exposures received in the United States were attributable to a viral variant associated with bats (Noah et al. 1998). The two remaining cases were attributable to rabies virus variants circulating in dogs and coyotes in the southwestern United States. Five additional cases were diagnosed in individuals who had lived or traveled abroad and received their exposure to rabies virus in another country. The viruses characterized from persons exposed in another country were all linked to variants circulating in dogs and endemic to the particular region where exposure occurred.

With the recognition of bat-associated rabies have come some unique challenges for the prevention of disease. In only one of the 19 bat-associated cases of human rabies reported from 1990 to 1997 was there clear evidence of bite. In several cases, a history of physical contact with a bat was reported by the patient or a family member, but no reliable history of bite was obtained. This lack of recognition of a bat bite or other contact known to be a risk factor for rabies virus transmission means that persons are not presenting to health providers for rabies PEP. Although the exact nature of human-bat contact resulting in rabies virus transmission remains unclear for many recent human cases, an undetected or an unreported bat bite remains the most plausible hypothesis. Rabies virus transmission other than by bite is rare and occurs under exceptional circumstances such as tissue (corneal) transplantation (Houff et al. 1979), accidental laboratory aerosolization of concentrated virus (Winkler et al. 1973), or exposure to aerosolized virus in caves inhabited by millions of bats (Constantine 1962).

An additional problem in the changing epidemiology of human rabies is the low level of clinical suspicion and timing of diagnosis, which may be linked to the lack of a clear exposure history health professionals normally associate with rabies virus transmission. As a result of this unclear history of exposure, many rabies cases are now being diagnosed postmortem. Two of the four rabies cases in 1997 were originally suspected to be Creutzfeldt-Jakob disease, delaying postmorten diagnosis and follow-up of other potentially exposed humans for weeks (Anonymous 1997b). In addition to the lack of bite history, the rarity of rabies in the United States makes diagnosis difficult. Any patient who presents with an encephalopathy of unknown etiology should be considered a potential rabies case, even in the absence of known rabies exposure through animal bite.

A final unusual finding in the cases of human rabies in the United States since 1990, was the identification of a rabies virus variant in 14 (74%) of the 19 cases as one almost exclusively found in either the silver-haired bat (*L. noctivagans*) or the eastern pipistrelle (*Pipistrellus subflavus*). These species of bats are rarely submitted for rabies testing (Childs et al. 1994) although their geographic ranges are extensive (Nowak 1994). Because rabies virus variants associated with a reservoir can also be found in other species during "spillover" events, the identification of a variant indicates the ultimate reservoir, if not the proximate animal source of infection.

Control and Prevention

Rabies PEP is expensive and not without risk of adverse reactions (Fishbein et al. 1989). Typically, increases in animal rabies result in increases in numbers of PEPs, and frequently rabies control programs aimed at reducing rabies in wildlife must be justified on the basis of potential cost savings. As an example, in New York State, the estimated number of persons receiving PEP increased from 84 in 1989, prior to the reintroduction of terrestrial rabies due to raccoons, to 1,125 in 1992 and 2,905 in 1993 (Anonymous 1994).

Interventions aimed at either reducing the incidence of rabies in wildlife or preventing the spread of rabies are ongoing in several states. Most of these programs are using a vaccinia-rabies glycoprotein (V-RG) recombinant virus vaccine as the vehicle to immunize animals. Similar programs using a variety of different vaccine types have been very effective in reducing the incidence of red fox rabies over much of western Europe (Pastoret et al. 1995). In the United States the efficacy of programs using V-RG contained within baits for ingestion by raccoons is under assessment in eastern Massachusetts (Cape Cod), eastern and northern New York State, southern New Jersey (Cape May), Florida (Pinellas County) and, most recently, Vermont and Ohio (Columbiana, Mahoning, and Trumbull counties) (Hanlon and Rupprecht 1998). Results of earlier trials designed to determine vaccine safety, efficacy, ecologic impact, and physical bait variables have been favorable (Rupprecht et al. 1988; Hable et al. 1992; Rupprecht et al. 1993; Hanlon and Rupprecht 1998). The V-RG virus vaccine was fully licensed in April 1997 for use in raccoons. In Texas, the same V-RG vaccine, packed in different bait, is being used for the potential control of rabies in both coyotes and gray foxes (Meehan 1995). Oral rabies vaccine distribution in each state is limited to authorized state or federal rabies control programs (Jenkins et al. 1998).

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OVERVIEW OF WILD PIG DAMAGE IN CALIFORNIA

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ABSTRACT: Pigs (*Sus scrofa*) were first introduced to California in 1769, and European wild boars were imported to Monterey County in 1925. Descendants of the domestic swine and European wild boars have bred and formed populations of wild pigs. By the mid-1960s 15 counties had populations of wild pigs. Today 45 of California's 58 (78%) counties have reported having populations of pigs. Wild pigs can cause significant damage to farm and rangelands, livestock, natural resources, environmentally sensitive habitats, and property. There are limited estimates of damage caused by wild pigs in California. A survey was sent to all County Agricultural Commissioners in California to document the extent and amount of damage occurring in 1996 and what control measures were taken to reduce the damage. Forty (40) counties responded to the survey and reported $1,731,920 worth of damage caused by wild pigs.

KEY WORDS: Pig (*Sus scrofa*), European wild boar, wild pig, damage, disease

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INTRODUCTION

Since first being introduced to North America, pigs have commonly been allowed to range and reproduce freely. As a result, they now occur in significant numbers throughout most states. In California, wild pigs currently occur in approximately 45 counties in California (Figure 1). Free ranging pigs frequently cause damage to natural resources, crops, livestock, and property.

Figure 1. Distribution of wild pigs in California (1996).

Damage to natural resource such as woodlands, and native plant communities is difficult to quantify and many times is unreported. However, with the increase in wild pig population and distribution, significant damage is accruing to property such as landscapes, golf courses, and agriculture (row crops, livestock, orchards, and irrigation systems).

A survey was sent to all County Agricultural Commissioners in California to collect data on damage caused by wild pigs.

Historical Background

Pigs (*Sus scrofa*) were first introduced by early settlers in North America in 1539 and California in 1769 (Barrett and Birmingham 1994). The early settlers utilized pigs for food and to clear land. Pigs were allowed to range freely to forage for mast crops throughout the oak woodlands of California, and scattered populations of feral pigs were soon established. In 1925, European wild boars were imported into Monterey County (Updike and Waithman 1996). Wild boars that escaped captivity readily bred with free ranging feral pigs to form a viable "wild pig" cross.

By the mid-1960s, as many as 15 counties had populations of wild pigs. According to recent surveys wild pigs have increased in population and expanded their range to at least 45 counties. Wild pigs have expanded their range by dispersing when rainfall patterns provide good forage conditions. In addition, considerable evidence suggests that humans illegally captured wild pigs, transported them to previously unoccupied areas, and released them primarily for hunting purposes (Updike and Waithman 1996).

The biology and ecology of wild pigs make them a very prolific species. Given sufficient nutrition, sows can have two litters a year, resulting in the potential for a wild pig population to double in approximately four months (Barrett and Birmingham 1994). Wild pigs are opportunistic omnivores and their diet may consist of a variety of plant material including mast, fruits, bulbs, and animal material including fish, snakes, frogs, insects, small mammals, birds, and livestock.

DAMAGE

Wild pigs can cause a variety of damage. They use their strong snouts and neck muscles to dig and overturn soil in search of grubs, insects, mast, root bulbs, plant material, and fungus. This rooting (also called grubbing) activity can result in the destruction of crops and pasture (USDA 1992). Rooting also damages irrigation systems, farm ponds, fencing, and native plants which can lead to soil erosion problems. Wild pigs rooting on golf course fairways and greens can cause considerable damage in a single night. Wild pig depredation on livestock and poultry can cause high economic loss (Choquenot et. al. 1996). Livestock predation usually occurs on or near the lambing or calving grounds. Wild pigs kill newborn lambs and calves and younger, less mobile individuals. Death usually occurs by biting and crushing the skull or neck. Wild pigs also violently shake their victims causing injury and/or death. It is common for pigs to completely consume a carcass, leaving no evidence an attack occurred.

If the carcass is not entirely consumed, wild pig predation can sometimes be determined by characteristic feeding patterns (Pavlov and Hone 1982). Wild pigs can carry a number of diseases and parasites that can be transmitted to livestock, wildlife, and humans. In California, wild pigs can be carriers of Brucellosis, Cholera, Leptospirosis, Tuberculosis (Bovine, Avian, and Swine), Q fever, Trichinosis, Toxoplasmosis, Pseudorabies, and Plague (Barrett and Tietje 1993).

DAMAGE SURVEY

Although damage caused by wild pigs is easily identified, estimates of the economic value are limited. Producers in Texas and California reported to United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) Wildlife Services (WS) that 1,473 sheep, goats, and exotic game animals were killed by wild pigs in 1991 (Barrett and Birmingham 1994). Depredation to calves and lambs can be difficult to identify because these small animals may be killed and completely consumed, leaving little or no evidence to determine whether they were killed or died of other causes and then were eaten.

A survey was sent to all County Agricultural Commissioners in California to document damage caused in California to crops, livestock, and property in 1996.

SURVEY RESULTS

Surveys to document wild pig damage were sent to all 58 California County Agricultural Commissioners. Forty of the 58 (69%) (Figure 2) counties responded to the survey. The 40 responding counties reported a total of $1,731,920 in wild pig damage (Table 1).

All counties that reported damage, reported that rooting was the major damage type. Nine counties reported predation on livestock. Nine counties reported wild pigs rooting was causing significant erosion. Six counties reported wild pigs eating or causing damage to crops. Six counties responded that wild pigs either moved or introduced disease in the county. Ten counties reported damage caused to fruit trees or grapevines from wild pigs using them as scratch or rubbing posts.

Detailed description of areas in California that sustained extensive damage from wild pigs is listed below.

Figure 2. Reported wild pig damage in California (1996).

Mendocino County

Mendocino County reported that wild pigs caused $65,500 in damages to pasture and rangeland. An estimated 4,000 acres (1,600 ha) were rooted in the last year at a cost of $40,000. The second leading cause of damage was estimated at $20,000 for rebuilding damaged or installing new fences around properties to prevent further damage from wild pigs. Damage was also documented to residential lawns and small vineyards, however, no dollar figure was available. The California Department of Fish and Game (CDFG) issued two depredation permits in 1995 and three in 1996. Hunter surveys for 1995 and 1996 recorded there were 1,742 and 1,501 wild pigs taken, respectively.

Contra Costa County

The Contra Costa Water District is investing $5 million into a wetland and oak woodland mitigation project to the Los Vaqueros Project. As part of the mitigation agreement, the Water District must preserve and enhance a variety of habitat types for wildlife. Wild pigs have caused extensive damage to these newly developed habitats. For example, wild pigs severely damaged a 38 acre (15.2 ha) area of newly planted oaks the night after planting. There are numerous plant and animal endangered species that occur in the Los Vaquerous Watershed Area that could be negatively impacted by habitat destruction caused by pigs. The Water District is currently working to reduce damage, under a depredation permit issued by CDFG. However, the permits are limited on the number of animals that can be taken.

Table 1. Results of wild pig damage and harvest data for the 40 counties responding to the survey.

County	Resource Damaged	Dollar Value	Complaints	Permits[1] 1995-1996	Hunter Harvest[2] 1995-1996
Alameda	hay/forage/ponds	11,500	increasing	1-4	493-308
Alpine[3]					
Amador	lawns	100	same	0-0	0-38
Butte	lawn/range/drainage	500	same	1-0	0-269
Calaveras	lawn/range/ponds	10,500	increasing	0-0	0-0
Colusa	orchards/vineyards/ponds	50,000	increasing	0-0	526-154
Contra Costa	lawn/range/pond/irrigation	130,000	increasing	2-4	66-38
Del Norte[3]					
El Dorado					0-77
Fresno	livestock/hay/tree/irrigation	62,720	increasing	2-3	658-539
Glenn	livestock/crops/ponds	9,500	increasing	0-0	66-616
Humboldt[3]				1-1	99-38
Imperial[3]					
Kern	crops/pasture/ponds/irrigation	14,000	increasing	0-0	99-423
Kings	pasture/ponds	2,600	same	0-0	296-539
Los Angeles[3]				4-1	33-0
Madera	pasture	2,000		0-1	132-154
Mendocino	fruit/pasture/ponds/drainage	66,500	increasing	2-3	1,742-1,501
Merced	nuts/irrigation	8,500	increasing	0-0	559-3,155
Modoc[3]					
Mono[3]					
Monterey[3]				7-20	4,537-2,501
Napa	hay/pasture/irrigation	6,500	increasing	4-2	395-77
Nevada	lawns/pasture/drainage	1,705	increasing	2-1	0-269
Orange[3]					
Placer	pasture/lawns/ponds	10,100	same	0-0	0-0
Plumas[3]					
Riverside	lawn/sod/ponds	2,000	increasing	0-2	66-154
Sacramento[3]					
San Benito	crops/calves/irrigation	858,700	increasing	10-21	1,381-1,963
San Luis Obispo	fruit/crops/irrigation	62,200	increasing	15-12	1,677-1,809
San Mateo	fruit/crops/irrigation	50,500	increasing	2-0	0-38
Santa Barbara	fruit/crops	0	increasing	1-2	888-2,501
Santa Cruz	crops/road/pond/drainage	253,200	increasing	50-30	395-308
Sierra[3]					0-30
Siskiyou	livestock/hay/ponds	1,400	same	0-2	0-38
Solano	fruit/pasture/ponds	4,500	increasing	3-7	197-77
Sonoma	livestock/pasture/irrigation	79,000	increasing	3-3	2,301-1,231
Stanislaus	lawn/pasture/irrigation	6,250	same	0-0	888-462
Sutter	livestock/nuts/ponds/irrigation	19,000	increasing	5-4	0-77
Tehama	pasture/nut/pond/drainage	7,500	same	9-2	132-885
Tuolumne	livestock/lawn/drainage	700	increasing	0-0	33-38
Yuba	rangeland/pasture/drainage	250	same	0-0	0-0
Total		1,731,290			

[1]CDFG Depredation Permit Reports.
[2]CDFG Hunter Take Survey 1995 to 1996.
[3]Counties responded no damage.

East Bay Regional Park District (Park). The Park is a public agency that maintains open space in several counties around the San Francisco Bay. The Park District has had a wild pig management program in place since 1993 in seven parks. The overpopulation of wild pigs has caused extensive damage to natural resources which has direct negative impacts on the area's endangered species. Wild pigs in the parks have caused a human health and safety concern with several incidents of wild pigs charging district employees and, on one occasion, charging a group of school children. Damage caused to turf and irrigation systems is approximately $10,000 annually. The Park District has 300 ponds and estimates a cost of approximately $2,500 to $5,000/pond to exclude wild pigs. The Park District spends in excess of $60,000 a year to reduce wild pig damage within the seven parks.

Residential subdivisions/golfcourse. Four residential subdivisions and one golf course sustained approximately $64,000 per year for wild pigs rooting turf and ornamental plants. A total of 31 residential properties have suffered wild pig damage to their landscape.

San Benito County

Wild pigs have caused $858,700 in damages to walnuts, vineyards, grains, golf course turf, predation to calves, and transferring diseases to livestock. Diseases transmitted to domestic animals in 1996 cost between $10,000 to $15,000. Wild pigs caused $20,000 damage to native plants and property on the 16,000 acre (6,400 ha) Pinnacles National Monument. The cost to fence the national monument was priced at $600,000. Vineyards in the Park sustained approximately $35,000 in damages from wild pigs. The cost to replace and repair irrigation systems within the county was $14,500. The CDFG issued 10 and 21 depredation permits in 1995 and 1996, respectively. Hunter surveys recorded 1,381 and 1,963 wild pigs taken in 1995 and 1996, respectively.

San Mateo County

Wild pigs caused $635,000 in damage to kiwi, artichokes, cut flowers, and peas in San Mateo County. There are 13 threatened and endangered plant species in this county. The CDFG issued two depredation permits in 1995 and none in 1996. Hunters removed zero wild pigs in 1995 and 38 in 1996.

Santa Cruz County

A total of $252,200 in damages was reported. Artichokes and leaf lettuce combined for a total of $161,000 in damages. Rooting of pasture and rangeland totaled 962 acres (390 ha) with a damage value of $13,000, while pumpkins, sweet corn, and oat hay totaled $7,200. Road and trail maintenance cost $5,000 and fence improvements cost $6,000. The Office of the Agricultural Commissioner in Santa Cruz County states that the above figures are minimal compared to the true economic and environmental impact that the wild pigs are having on the county. There is 1,000 miles (1,600 km) of permanent stream in the county of which over 500 miles (800 km) have experienced some type of damage such as wallowing, repeated stream crossings, and rooting up of aquatic vegetation, which is detrimental to stream and water quality. It is estimated that over two percent (2%) of the county's wetlands, 20 miles (32 km) of riparian habitat, and 2,200 acres (880 ha) of forest land have sustained damage which has also impacted the water supply to ranchers, small farmers, and homeowners. Property owners in the Santa Cruz Mountains who get their water supplied to them by spring, must fence around the springs or face a deficiency in their domestic and irrigation water. There are 10 plant species listed on the threatened and endangered species list. According to CDFG there were 50 depredation permits issued in 1995 and 30 permits issued in 1996. The hunter survey indicated that 395 and 308 wild pigs were harvested in 1995 and 1996, respectively.

San Luis Obispo County

San Luis Obispo County reported $62,200 in damages caused by wild pigs to orchards and property. Wild pigs caused damage to avocados, citrus, row crops, oriental fruits, and vegetables throughout the county. Wild pigs not only cause damage by eating the fruit in the orchards, they also cause damage by tusking (debarking) trees and damaging drip-line irrigation systems. Nets installed in feijoa orchards to catch falling fruit are damaged by pigs searching for the ripening crop. One orchardist reported wild pigs were causing the spread of Phytophthora Root Rot, a fungal disease in the soil. Wild pigs rooting and disturbing feeder roots reportedly spread this fungal disease throughout the orchard.

CONCLUSION

Since the 1960s, wild pigs have expanded their range from 15 counties to presently over 45 counties. This expansion has increased the number of complaints received about wild pig damage. Damage has also expanded to a wider variety of resources affecting both rural and urban areas. This survey represents a small percentage of the actual damage occurring in the state. There is a need for a more long-term indepth reporting process to track wild pig damage. Until such a system is in place the overall significance of the problem will never be fully documented.

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CHANGES IN WILD PIG DEPREDATION IN CALIFORNIA: A NEW LAW

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INTRODUCTION

Wild pigs (*Sus scrofa*) are exotic large mammals inhabiting much of California. The foraging behavior (rooting) of these prolific animals disturbs soil much like rototilling. This disruptive behavior is a major point of contention for public land managers and private landowners, especially owners of small parcels of private land.

Wild pigs are lawfully defined as game mammals (Section 3950, Fish and Game Code). As such, no part of a wild pig that would normally be eaten by humans can be legally left to waste in the field (Section 4304, Fish and Game Code). There are provisions (Sections 4181 and 4181.1, Fish and Game Code) that allow the taking of wild pigs causing damage to private property with a depredation permit issued by the California Department of Fish and Game. Animals taken under the authority of a depredation permit are required to be properly cared for (eviscerated) and made available to non-profit organizations for human consumption. This process has been deemed too cumbersome by many private landowners who have property damaged by wild pigs.

In December 1993, the California Fish and Game Commission adopted a new policy for wild pigs in California. The policy states: "The wild pig population of the state must be controlled to minimize the threat of increasing damage to California's native plants and animals, to agricultural operations, and to park and recreational activities from the foraging habits of the animals. Consistent with state law and regulations, the Department will prepare and recommend to the Commission regulations which enhance recreational hunting and facilitate the issuing of depredation permits and/or other legally available means to alleviate this problem."

As mandated by current law (Fish and Game Code, Section 4651), the Department of Fish and Game prepared a Wild Pig Management Plan in 1995 (Waithman 1995). This strategic plan contains information related to the status and trend of wild pig populations, and describes management units established by the Department to address regional needs and opportunities. Updike and Waithman (1996) summarize the planning process and the contents of the plan. The highest priority action identified in the plan is alleviating damage of private property caused by wild pigs. One of the management actions prescribed by the plan involves amending current statutes to facilitate alleviating property damage.

BACKGROUND

The history of wild pigs in California dates back to the mid-1700s when they were introduced by European settlers as livestock. Historical journals indicate that domesticated pigs were allowed to forage in oak woodland areas to take advantage of acorn crops. As a result of this practice, some pigs escaped and this created wild, free-ranging feral populations. Additional pigs escaped to the wild as California was explored and developed through the 1800s and early 1900s. In the early 1920s, European wild boars were imported into Monterey County by a landowner in Carmel Valley under a domesticated game breeder's permit. Some animals escaped and dispersed into central coastal areas where they bred with feral domestic pigs.

Wild pigs occurred in relatively low numbers in 10 to 15 counties until the mid-1960s. Since then, wild pig numbers have increased, and they have expanded their range, primarily in coastal counties from Humboldt to Santa Barbara. Recent surveys indicate that wild pigs occur in at least 47 counties (Figure 1).

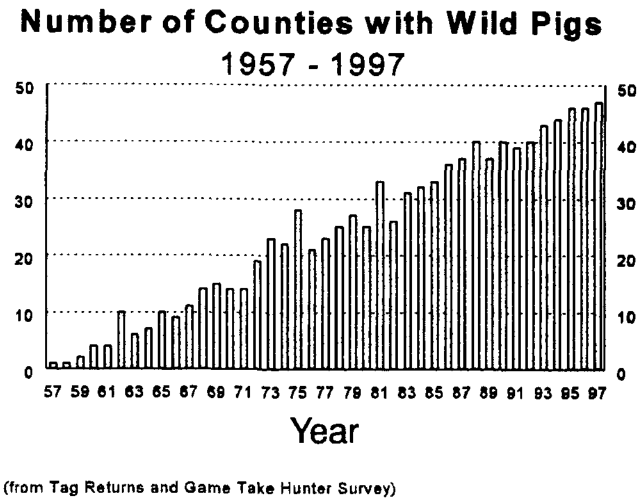

Figure 1. Number of counties occupied by wild pigs from 1957 to present.

The number and location of depredation permits issued by the Department of Fish and Game reflect the distribution of wild pigs (Figure 2).

In 1957, wild pigs were classified as game mammals by the California State Legislature. The intent was, in part, to recognize the valued status of the European wild boar for hunting purposes. However, wild pigs can be distinguished from other game mammals because: 1) pigs are not native to California; 2) they are very productive; 3) they can cause serious damage to property; and 4) they disrupt native plant and animal communities.

Relative Pig Density Depredation Permits

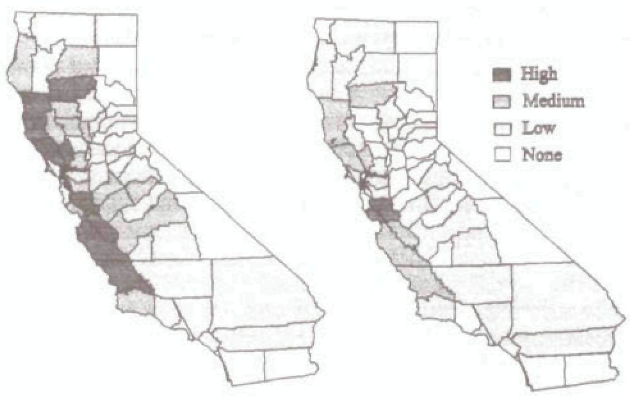

Figure 2. Relative density of wild pigs (map on left) and counties where depredation permits are issued (map on right).

In 1992, Sections 4650 through 4657 (Fish and Game Code) were amended to require hunters to possess wild pig license tags to hunt wild pigs. When a wild pig is taken, hunters are required to place a portion of the tag on the wild pig carcass and complete and return the report end portion of the tag to the Department.

The dual role of the wild pig as an exotic species and a game mammal presents a challenge to the Department. There is a great demand for recreational hunting, while wild pigs damage property and disrupt native plant and animal communities. A simple solution to the problem seems to be to let hunters take the wild pigs causing the damage.

Some public lands (e.g., parks) do not, or cannot allow hunting. Many private landowners do not want hunting on their property. They also may not want to follow all the required steps for using a depredation permit, especially actions to care for the carcass. In addition, there have been disagreements about whether the wild pig activity actually constitutes property damage. These and similar issues have been a major source of frustration for many landowners who have been invaded by depredating wild pigs.

NEW LAW

On January 1, 1998, a new law (SB329, McPherson) related to wild pigs became effective. This bill provides a variety of changes intended to help alleviate wild pig depredation and facilitate hunting were feasible. The major issues which the new law addresses are immediately taking the depredating pig and more liberal disposal of the carcass.

The new Section 4181.1(b), Fish and Game Code allows the immediate taking of a depredating wild pig by the owner of livestock, land or property, or the owner's agent or employee, or employee of any federal, state, county or city entity while acting officially. This change greatly expands the number of persons authorized to immediately kill wild pigs which are encountered while in the act of damaging livestock or damaging, destroying, or threatening to immediately damage or destroy land or other property. Damage to livestock includes injury to, molesting, pursuing, worrying, or killing of livestock. Other property includes, but is not limited to, rare threatened or endangered native plants, wildlife or aquatic species. Section 4181.2 defines damage as loss or harm resulting from injury to person or property, and requires the Department of Fish and Game to develop statewide guidelines to aid in making determinations of damage caused by wild pigs. The guidelines shall consider various uses of the land impacted by the pigs.

The new law does not supercede any local ordinances or regulations related to the discharge of firearms. Consequently, some landowners within city limits or other areas with firearm restrictions may not receive much benefit from the changed statutes.

Section 4181.1(b) also provides for more liberal disposition of the carcass of depredating wild pigs which are immediately killed. Within the next working day, the person taking the wild pig is required to report the taking to the Department and make the carcass available to the Department. Unless otherwise directed by the Department, the person who takes the wild pig may keep and use the carcass, or it can be possessed by a designated person in an arrangement for transfer. If an "arrangement for transfer" of the carcass is made by the person taking the depredating wild pig, the person who made the arrangement is deemed in compliance with the wanton waste statute (Section 4304, Fish and Game Code). This means that landowner concerns about carcass disposal are greatly alleviated. One enforcement difficulty for the Department is defining an "arrangement for transfer." The arrangement could be a simple verbal agreement without written documentation. Consequently, wild pig carcasses could legally be transported from one place to another without being tagged.

The new law encourages the Department to include the use of licensed hunters to take depredating wild pigs by adding wording to the Wild Pig Management Plan. To further facilitate removal of depredating wild pigs by licensed hunters, the plan may investigate means to live trap depredating wild pigs and transport them to areas where they can be hunted. The Department has concerns about trapping and translocating wild pigs. One major issue is potential disease transmission between populations of wild pigs and between transported wild pigs and domestic swine. Another concern is potentially expanding the range of wild pigs into areas where they may cause damage. Finally, the Department does not have the personnel and equipment necessary to conduct the trapping and translocation projects. Guidelines for trapping and translocating depredating wild pigs would need to address all these issues for it to be a feasible alternative.

The law specifies that lists of license hunters may be made available to landowners who request a depredation permit. Some non-profit hunting organizations have volunteered for managing the list of hunters. Finally, the law encourages managing a list of non-profit organizations who would assist with the removal and disposition of carcasses. This list could be provided to persons who request depredation permits. Agricultural Commissioners of some counties with depredating wild pigs have volunteered their assistance in accomplishing this task.

CONCLUSION

The new law authored by Senator McPherson makes several major changes in the way landowners in California can deal with damage caused by wild pigs. The definition of damage has significantly changed to include effects on other wildlife and aesthetics. The new law expands the list of persons authorized to take wild pigs immediately when they are damaging or threatening damage to private property. In these situations, a wild pig may be taken without a depredation permit or wild pig hunting license tag. This causes some enforcement problems for the Department. The options for disposing of depredating wild pigs has expanded, and making an arrangement for transfer of the carcass is deemed compliance with wanton waste statutes. Additional emphasis is added to facilitate use of licensed hunters to remove depredating wild pigs, including trapping and translocating them to areas where they can be hunted. The Department is concerned about translocations causing an expansion of the range of this exotic species and implications to the spread of disease.

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DEER ON AIRPORTS: AN ACCIDENT WAITING TO HAPPEN

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ABSTRACT: The authors analyzed data on civil aircraft strikes with wild ungulates (deer [*Odocoileus* spp.], elk [*Cervus canadensis*] and moose [*Alces alces*]) in the U.S. from the Federal Aviation Administration (FAA) Wildlife Strike Database and the National Transportation Safety Board (NTSB) Aviation Accident Database for 1983 to 1997. Prior to 1991, the FAA Form 5200-7 for reporting strikes was designated solely for bird strike data, thus, strike reports for non-avian species prior to 1991 are underrepresented. A total of 343 ungulate strikes was reported, 48 from 1983 to 1990 and 295 from 1991 to 1997. Forty-four states reported ungulate strikes with 77% of the reports from states east of the Mississippi River. November had more ($P < 0.01$) strikes (23%) than any other month. The strike rate (number/hr) was four to nine times greater ($P < 0.01$) at dusk than at night or dawn. Almost two-thirds of strikes ($P < 0.01$) occurred during landing, making landing at dusk in November the most likely time for deer strikes. About 79% of strikes had an effect on flight. Aircraft were damaged in 83% of strikes. Only 14% of reports indicating damage provided estimates of cost of repairs. The mean cost for these reports was $74,537. Reported human injuries have been few, but the potential exists for a major disaster. Aircraft with capacity of 101 to 380 passengers were involved in 45 (14%) of the reported strikes. Airports should adopt a "zero tolerance" for deer within the operations area. Deer removal by professional shooters, in conjunction with permanent exclusion with 3 m high fencing, is the preferred management action.

KEY WORDS: airplane, airport, collision, deer, *Odocoileus virginianus,* strike, vertebrate pest, wildlife damage

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INTRODUCTION

There has been a dramatic increase in the white-tailed deer (*Odocoileus virginianus*) population in the United States in recent years. In 1900, white-tailed deer had been hunted to near extinction with only about 100,000 remaining, but they now number over 26 million (Jacobson and Kroll 1994). In addition to white-tailed deer, other ungulates whose populations have recovered include mule deer (*O. hemionus*), elk, and moose. In this paper, all wild ungulates are referred to as deer unless specifically noted otherwise.

Deer-automobile collisions are becoming more common in the U.S., increasing from an estimated 200,000 incidents in 1980 to 538,000 in 1991 (Romin and Bissonette 1996). However, most people are unaware that deer collisions with aircraft are also a serious problem. Airports often are situated in outlying areas surrounded by woods, agricultural fields, and early successional habitats. Landing fields, planted with grasses and forbs, provide prime locations for grazing.

The authors' objectives were to document the extent and characteristics of deer/aircraft collisions in the U.S. and to discuss methods to reduce these collisions. Their goal is to make airport managers, pilots, and the public more aware of the seriousness of deer/aircraft collisions so that more effective management programs can be put in place at airports.

METHODS

The data for this study were taken from two sources, the FAA Wildlife Strike Database and the NTSB Aviation Accident Database. The former relies on voluntary reporting of strikes to the FAA by pilots and other aviation personnel (primarily on FAA Form 5200-7). The latter comprises information collected by the NTSB during investigations of accidents or incidents involving civil aircraft. This study did not include incidents with military aircraft.

Form 5200-7 has been available since the 1960s; however, no quantitative analyses of strikes were done until 1995 (Dolbeer et al. 1995). In April 1995, the U.S. Department of Agriculture's National Wildlife Research Center, through an interagency agreement with the FAA, initiated a project to obtain more objective estimates of the magnitude and nature of the wildlife strike problem nationwide for civil aviation. This project included: 1) editing all strike reports (Form 5200-7) sent to the FAA to ensure consistent error-free data; 2) entering all edited strike reports into a wildlife strike database; and 3) supplementing FAA-reported strikes with additional non-duplicating strike reports from other sources (e.g., NTSB, Aviation Safety Reporting System, engine manufacturers and others [Cleary et al. 1997]). In addition, phone calls were sometimes made to obtain additional details about strikes where incomplete data were submitted. Using this approach, the authors have presently (February 1998) compiled data on all reported wildlife strikes for 1991 to 1997. In addition, data were obtained for some deer strikes going back to 1983 (Form 5200-7 did not request data on wildlife other than birds until 1991).

RESULTS

Characteristics of Strikes

A total of 343 ungulate strikes was reported from 1983 to 1997, 48 from 1983 to 1990 when strikes were inconsistently reported, and 295 from 1991 to 1997 when records were more complete (Figure 1). From 1991 to 1997, there was a mean of 42.1 strikes/year: the most and fewest strikes reported in a year were 58 (1996) and 26 (1991). Species reported struck included 222 unidentified deer, 113 white-tailed deer, 5 elk, 2 moose, and 1 mule deer. Of the 121 ungulates identified to species, 93% were white-tailed deer.

Of the 44 states reporting deer strikes, 26 states east of the Mississippi River reported 77% of the strikes. States having the most deer strikes were West Virginia, Pennsylvania, New Jersey, Michigan and New York (Table 1). Most states (38) averaged <1 deer strike report/year.

Deer strikes were not evenly distributed throughout the year (X^2 = 151.6, 11 df, $P < 0.01$). November had 23% of the reported strikes, more than in any other month (Figure 2). For October to November, which represents 17% of the year, 40% of all deer strikes were reported. The fewest number of strikes was reported for the January to May period (21%).

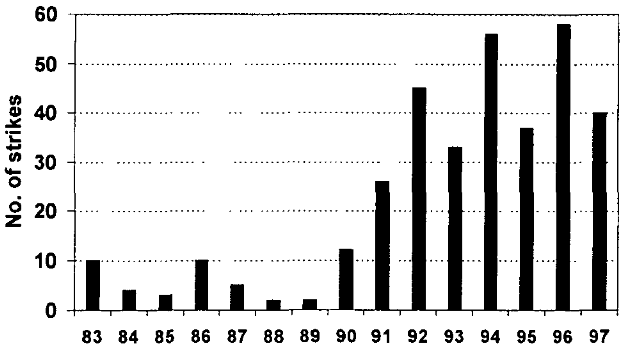

Figure 1. Number of reported ungulate strikes by year to civil aircraft, U.S., 1983 to 1997. Data were inconsistently collected before 1991.

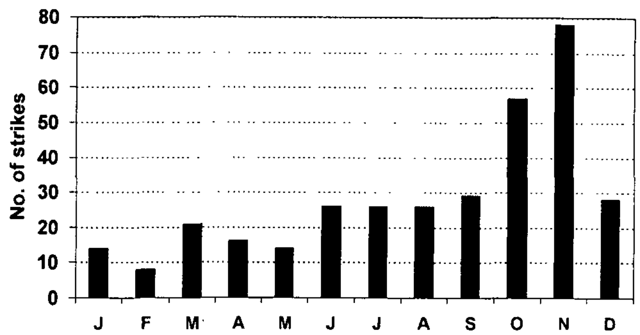

Figure 2. Number of reported ungulate strikes by month to civil aircraft, U.S., 1983 to 1997.

Table 1. States having 10 or more reported ungulate strikes to civil aircraft, 1983 to 1997.

State	Strikes Number	Strikes Percent
West Virginia	33	10
Pennsylvania	31	9
New Jersey	25	7
Michigan	24	7
New York	21	6
Virginia	17	5
Maryland, Ohio, Texas, Wisconsin	11 each	13
Connecticut, Illinois, North Carolina, Missouri	10 each	12
All others	108	31
Total	343	100

Given that dusk and dawn average 0.75 hours each; and day and night average 11.25 hours each, deer strikes with aircraft occurred most often ($P < 0.01$) at dusk (69 strikes/hr) followed by night (17 strikes/hr) (Table 2). Almost nine times more strikes occurred at dusk than at dawn ($X^2 = 36.48$, 1 df, $P < 0.01$).

More strikes happened during approach/landing (63%) than during take-off/climb (36%) [$X^2 = 23.78$, 1 df, $P < 0.01$]. Less than 1% of strikes occurred during taxiing (Figure 3).

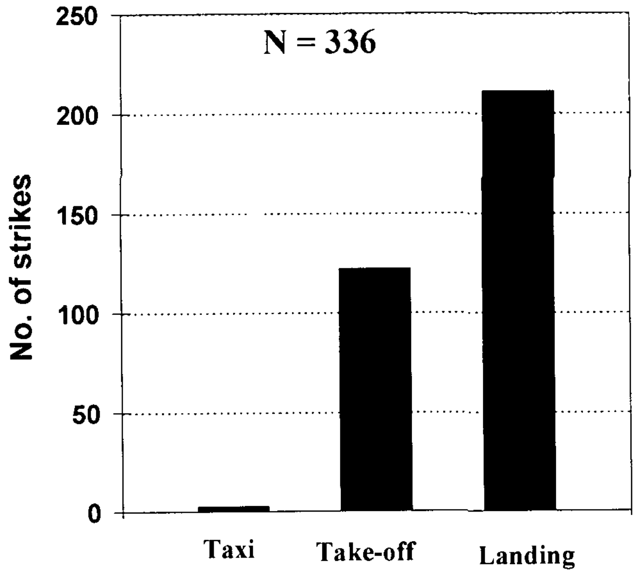

Figure 3. Number of reported ungulate strikes by phase of flight to civil aircraft, U.S., 1983 to 1997.

Most strike reports (41%) were from businesses followed by private owners (33%) and commercial airlines (26%). Aircraft with the capacity for 1 to 10 passengers were involved in the majority (65%) of reported strikes. Aircraft which carry 101 to 380 passengers were involved in 14% of the strikes (Table 3).

Effect of Strikes

Strikes had an effect on flight in 79% of the reports where effect was recorded. Effects included: aborted take-off (20%), precautionary landing (10%), engine shut down (2%), and other negative effect (47%) (Table 4).

The aircraft was damaged in 87% of the reported deer strikes (Table 4). The aircraft part most commonly struck was the landing gear (116) followed by the propeller (59) and the wing (53). The part most often damaged was the landing gear (106) followed by other (i.e., any part not listed on Form 5200-7) (56) and wing (55). Damage was substantial in 42% of the reports (Table 4). Twelve aircraft were destroyed.

Reports rarely showed the cost of deer-related damage; only 14% of the reports indicating damage provided estimates of cost of repairs. Based on data from strike reports which provided damage costs, the mean cost per deer strike was $74,537, or $21.2 million for the 285 reported damaging strikes. However, the authors believe this figure considerably underestimates the true cost. For example, none of the strike reports obtained from the NTSB database (53, 15% of total), which were all classified as substantial damage, had cost estimates. The most expensive strike reported ($1.4 million) was to a Hawker-Siddeley in which an engine was torn loose from the aircraft after hitting a deer at 160 kph on take-off.

Table 2. Reported time of day for ungulate strikes to civil aircraft, U.S., 1983 to 1997.

	Strikes		
Time of Day	Number	Percent	Number/hour[a]
Dawn	6	2	8.0
Day	72	23	6.4
Dusk	52	16	69.3
Night	190	59	16.8
Total Reported	320	100	
Not Reported	23		
Grand Total	343		

[a]Assumes 0.75 hour for dusk and dawn, and 11.25 hours for day and night. The strike rate/hour differed among time periods (X^2=242.4, 3 df, $P < 0.01$).

Table 3. Reported operator type and capacity of civil aircraft involved in ungulate strikes, U.S., 1983 to 1997.

	Strikes			Strikes	
Type of Operator	Number	Percent	Passenger Capacity	Number	Percent
Commercial passenger	87	26	101-380	45	14
Business	138	41	51-100	6	2
Private	109	33	11-50	63	20
Total	334	100	≤10	209	65
Unknown	9		Total	323	100
Grand Total	343		Unknown	20	
			Grand Total	343	

Table 4. Effect of flight and amount of damage to civil aircraft by ungulate strikes, U.S., 1983 to 1997.

	Strikes			Strikes	
Effect on Flight	Number	Percent	Amount of Damage	Number	Percent
Engine shut down	4	2	None	43	13
Precautionary landing	26	10	Unknown extent	4	1
Aborted take-off	50	20	Minor	132	40
Other negative effect	117	47	Substantial[a]	137	42
None	52	21	Destroyed	12	4
Total reported	249	100	Total reported	328	100
Not reported	94		Not reported	15	
Grand total	343		Grand total	343	

[a]Damage which adversely affects the structure strength, performance, or flight characteristics of the aircraft, and which would normally require major repair or replacement of the affected component (ICAO 1989).

Reported human injuries from deer strikes have been few, perhaps because injury reports are not specifically required on the 5200-7 Form. The only serious injury reported was in 1992 in Minnesota. The pilot in a Piper Cherokee hit a deer at rotation. When he attempted to turn back to the airport the airplane crashed 0.5 km south of the airport into trees. The pilot was seriously injured and the aircraft was destroyed.

DISCUSSION

Characteristics and Effects of Strikes

Although deer/car collisions have dramatically risen (Bellis and Graves 1971), there is no significant trend of increasing deer/aircraft strikes since 1991. The apparent increase from the 1980s to the 1990s is probably due to increased reporting of deer strikes which were not regularly reported before 1991. Even with the increased reporting of strikes from 1991 to 1997, many strikes go unreported for various reasons. Cleary et al. (1997) estimated that 80% of wildlife strikes to civil aircraft are unreported.

There are presently about twice as many white-tailed deer east as there are west of the Mississippi River (Jacobson and Kroll 1994). The fact that 77% of the reported deer/aircraft collisions were in the eastern U.S. is likely related to the higher population of white-tailed deer compared to the west. About 93% of identified ungulate strikes were caused by white-tailed deer.

The seasonal pattern of most aircraft/ungulate strikes occurring in October to November follows the same trend as with automobile/ungulate strikes (Bellis and Graves 1971). Deer are on the move at this time of year because of the rut (Hawkins et al. 1971). Young bucks are being chased off by adult bucks who are also busy courting does. As expected, most strikes occurred at night or during crepuscular periods when deer are most active (Carbaugh et al. 1975) and difficult to see.

Approximately twice as many strikes occurred during landing as opposed to take-off. This may be due to engine power reduction on landing which diminishes engine noise, allowing the aircraft to surprise the deer. In addition, deer may be more visible to pilots at take-off than at landing, unless it is dark. These findings point to the fact that both pilots and airport managers need to be especially aware of the increased likelihood of deer strikes during evening landings in the autumn.

The data indicated that 87% of the deer strikes from 1983 to 1997 caused damage to the aircraft and 45% of the aircraft struck had substantial damage or were destroyed. In contrast, only 16% of the 11,253 bird strikes reported from 1992 to 1996 caused damage (Cleary et al. 1997). Thus, although ungulate strikes comprise only about 1.9% of the total reported wildlife strikes (Cleary et al. 1997), they are over five times more likely to cause damage than birds. Deer strikes must be taken seriously.

One final point regarding strike characteristics is that since 1983 there have been 45 strikes with aircraft which carry 101 to 380 passengers. If one of these large carriers had ingested a deer into an engine during take-off, the result likely would have been devastating. More aggressive management is needed to prevent such a catastrophe from happening. In addition to aircraft damage and potential loss of human lives from deer/aircraft collisions, airport operators may be held liable for such collisions if adequate wildlife management plans are not in place (Hoff 1995).

Management Actions to Reduce Strikes

Because of the potential consequences of deer strikes, airport mangers should establish a "zero tolerance" policy for deer within aircraft operating areas (AOA). However, deer management can be complex and each airport has unique features. Therefore, airport managers with deer problems should request help from professional wildlife biologists trained in wildlife damage control to assess hazards and provide recommendations.

There are four basic management practices available to minimize deer numbers in an AOA: 1) exclusion; 2) population removal; 3) habitat management; and 4) harassment. The most secure protection against deer hazards is total exclusion with fencing (Craven and Hygnstrom 1994) done in conjunction with population removal. Deer can jump 2.4 m high fences (Sauer 1984); therefore, 3 m fencing with an additional three strands of barbed wire on top is recommended. Fences must be maintained so there are no gaps along the ground or at entry gates. Cattle guards ($\geq$4.6 m length) are effective in keeping deer from entering through gates that must be left open at times (Belant et al. 1998a).

Population removal requires close cooperation with state wildlife agencies for permits and approved methods. The safest and most humane removal technique is to have experienced sharpshooters work in conjunction with airport operations and safety personnel (Ishmael and Rongstad 1984; Montoney 1994). Capture and relocation is generally not recommended due to the elevated mortality rate of relocated deer, the high costs involved in relocation, and the scarcity of suitable release sites (Jones and Witham 1990). The authors emphasize that population removal without exclusion provides only temporary relief because deer will repopulate the AOA.

Habitat management includes removing wooded and brushy areas adjacent to runways. Although more research is needed, planting grasses that are less palatable to ungulates, such as tall fescue (*Festuca arundinacea*) associated with a symbiotic fungus (Aldrich et al. 1993), may be a new approach to make runway areas less attractive to deer. Chemical odor and taste repellents may be suitable for small garden plots and ornamental trees (Conover 1987) but are impractical for airports (Belant et al. 1998b).

Harassment techniques can include pyrotechnics (fireworks), sirens, propane exploders, flashing lights, and vehicles. Deer typically habituate to these devices within a few days (e.g., Belant et al. 1996, 1998c). Harassment can be effective if selectively used immediately prior to aircraft take-offs and landings. Increased diligence in harassment is needed especially during aircraft landings at dusk in October to November when the probability of deer strikes is highest.

In conclusion, although exclusion and population removal are the most effective strategies for minimizing deer hazards, no single technique will be 100% effective or appropriate at all times. Deer are adaptable and their populations are dynamic. In addition, costs may limit options such as complete fencing on smaller airports. The best approach will be to integrate several methods into a comprehensive wildlife management plan that is periodically evaluated and updated. The important point, as the strike statistics from 1983 to 1997 indicate, is that deer constitute a serious safety hazard on airports that must not be ignored.

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POTENTIAL RISKS ASSOCIATED WITH THE LEGALIZATION OF EXOTIC PREDATORS SUCH AS THE FERRET (*MUSTELA PUTORIUS FURO*) IN CALIFORNIA

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ABSTRACT: The interest in possessing ferrets as pets has given rise to controversy between the "rights" of the individual to own the pet of their choice and the concerns for protection of wildlife in California. An overview of the legislative history in California illustrates the state's attempts at protecting native wildlife species from exotic wild birds and animals. Concerns as to the potential threats associated with the legalization of ferrets in California are warranted in light of the wildlife damage resulting from the deliberate introduction of ferrets in New Zealand and the non-native red fox in California. A framework to assess risks involved with introducing non-native species that may impact native wildlife is needed.

KEY WORDS: ferret, *Mustela putorius furo*, risk assessment, wildlife damage

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INTRODUCTION

There has been a long history of introduced species establishing in California through both accidental and deliberate introductions. Deliberate introductions have historically occurred with the assistance of acclimatization societies and persons involved in fishing, hunting, or trapping. The diverse topography found in California has contributed to the rich variety of native wildlife. However, greater than 20% of amphibian, reptile, bird, and mammal species are now federally and state listed endangered and threatened species. California's threatened, endangered and endemic species could be impacted by an unwise introduction of another exotic carnivore.

Over the last few years there has been a strong lobbying effort by ferret enthusiasts and the pet industry to legalize ownership of the ferret (*Mustela putorius furo*) in California. California and Hawaii are the only states that completely restrict the ownership of ferrets as pets. Numerous other states have legislated local prohibitions of ownership of the ferret. The desire to own a ferret as a pet has given rise to a controversy over whether an individual has a right to own the pet of their choice (California Domestic Ferret Association 1995; Lynch 1996) and the concerns for protection of wildlife, agricultural interests, and human safety in California. A decision to legalize an exotic species should be based on a scientific assessment of the potential risks. An overview of the legislative history aimed at protecting the integrity of the state's wildlife interests can assist in decisions affecting the legal status of the ferret. The authors' objective is to show that there is a potential risk associated with the legalization of ferrets in California and a need for a risk assessment. Secondly, an appraisal of the current process involved in the legalization of the ferret highlights the need for a framework for decisions regarding exotic introductions.

HISTORY

The popularization of the ferret as an exotic pet may have begun with the 1982 movie "The Beastmaster" in which the hero owned two ferrets (Hitchcock 1994). With little or no prohibition in 46 other states, the ferret increased in popularity as a pet. Ferret enthusiasts claimed that by 1991 there were approximately six million ferrets nationwide (Weisser 1991). Organized ferret groups began to lobby for removal of restrictions in the states that prohibited legal ownership.

In California, ferrets were originally prohibited by California Statutes of 1933 under Chapter 76, Section 1 which read, "It is unlawful to import or transport into this state, except as provided under Section 2, any wild bird or animal of the following species . . . weasel, *Mustela nivalis*: stoat, *Mustela erminae*: ferret, *Mustela furo* . . . and such other species of wild bird or animal which may be designated by the Fish and Game Commission when such species are proved to be undesirable and a menace to the native wildlife or to the agricultural interests of the state." Further, Section 7 states that "a 'wild bird or animal' as used in this act means any bird of the class aves or animal of the class mammalia or the phylum mollusca or of the class crustacea which is either not normally domesticated, or not normally native within the state." As rules and regulations governing importation of wild birds and animals were amended the definition of "wild animal" was altered. In 1974, the definition of "wild animal" was changed to be any animal . . . of the class Mammalia (mammals) . . . which is not normally domesticated in this state as determined by the commission (California Department of Fish and Game Code of Regulations, Title 14, Subdivision 3, Chapter 3, Section 671—Importation, Transportation and Possession of Wild Animals).

Despite these restrictions, private citizens could obtain permits to possess neutered male ferrets under a Fish and Game Commission exemption for neutered males of many wildlife species. The Commission eventually viewed the exemption as a loophole for the importation of illegal exotic wildlife into the state and a threat to the integrity of the state's wildlife and agricultural interests. Few agency employees were specialized enough to ascertain whether an animal had been neutered and biologists found that intact males were entering the state. These violations prompted a policy change by the Fish and Game

Commission. In 1986, males of all wild animal species including ferrets, lost their exemption status and all permits were denied (Weisser 1991). All neutered males previously owned legally in California were grandfathered in.

Ferret proponents began to actively campaign for a change in the legal status of the ferret through the legislature, claiming ferrets were not a threat to wildlife and were a domestic species that should enjoy legal status in California. In 1994, a California Legislature Assembly bill (AB No. 2497) "Wild animals: domestic ferrets" was introduced by Assembly Member Goldsmith. The bill would allow domestic ferrets "to be owned as pets without a permit as long as the owner of the ferret maintains, and can produce documentation showing that the ferret has been vaccinated." The existing language of section 2118 would be changed to remove the phrase that the ferret was a "menace to native wildlife, the agricultural interests of the state, or the public health and safety . . ." The bill failed as did a similar Senate bill (SB 55) which was submitted at a later date by Senator Kopp. SB55 failed on two attempts to pass the Senate Committee on Natural Resources and Wildlife by January 9, 1996.

Early in 1997, Assemblyman Goldsmith, with a series of co-authors, introduced another bill AB 363. The bill was opposed by a coalition of California organizations comprised of the National Audubon Society, Sierra Club California, California League of Conservation Voters, Planning and Conservation League, California Waterfowl Association, and California Farm Bureau Federation. This coalition recommended a risk assessment be undertaken prior to legalization. The bill was amended to issue licenses to all ferrets currently in California. Ferret owners would have until June 30, 1998 to license their ferrets. Monies generated from licenses would fund a two-year study to assess the risk of legalization of ferrets on wildlife, public health, and agriculture. The bill would also authorize the Department of Fish and Game to eliminate feral ferret colonies when located (Legislative Counsel's Digest 1997). In July 1997, the Senate Natural Resources and Wildlife Committee voted 7-1 to pass the bill through the committee. A delay occurred shortly after the committee vote and the bill went "on call." The bill did not pass to the Senate floor in the required time.

In addition to their efforts to change legislation, ferret proponents have also appealed directly to the Fish and Game Commission to lift the restrictions on possession of ferrets in California. Their appeals were based on their opinion that ferrets were no threat to wildlife and, secondly, that ferrets were domestic animals that should be free from restrictions placed on introduced wild animals. All efforts to change the status of the ferret through these appeals to the commission were unsuccessful. Consequently, in December 1996, Marshall Farms, USA, Inc. filed a lawsuit in Superior Court in San Diego County against the California State Fish and Game Commission. The lawsuit sought to command the Commission to "fulfill its mandatory statutory duty to determine whether the ferret is an animal that is 'normally domesticated' in the State of California." A recent decision in Superior Court in San Diego County found on behalf of Marshall Farms (R. Christenson, pers comm). The court has instructed the Fish and Game Commission to adopt new regulations for the ferret. An appeal process is underway, and action by the Fish and Game Commission is unlikely until such time as an appeal process is complete.

RISK ASSESSMENT

There is considerable uncertainty regarding potential risks to native wildlife associated with the legalization of the ferret in California. Ferret proponents claim that escaped or released ferrets would be unable to survive in the wild. Several factors including a high risk of predation and the condition of hyperestrogenism in the female have been cited (California Domestic Ferret Association 1995; Lynch 1996). However, there are many documented incidences of ferrets surviving or establishing populations in the wild, and negatively impacting wildlife. Ferrets survive in the presence of other mammalian predators like the red fox in England where escaped ferrets have become well established in the northern portions of the country (Macdonald 1995). Feral ferret populations have become established in the wild on the Scottish islands of Arran and Bute, on the Isle of Man in the Irish Sea, and on the Isle of Anglesey off the Coast of north Wales, as well as in Renfrewshire and parts of Yorkshire (Walton 1977). An isolated population of ferrets was reported existing to the south of Launceston in Tasmania, Australia, but it is uncertain if the population persists today (Bomford 1991; Wilson et al. 1992). Ferrets also have been documented from the 1970s into the early 1980s on San Juan Island in Washington State (Weisbrod et al. 1976; Stevens 1975, 1982,). Healthy ferrets have been trapped on Revillagigedo Island and Joe Island from 1985 to 1986 off the Southern coast of Alaska (Alaska Department of Fish and Game, pers. comm.).

The largest feral population of ferrets occurs in New Zealand (Lavers and Clapperton 1990). The large number of wild ferrets there resulted from numerous deliberate releases of ferrets, European polecats (*Mustela putorius putorius*) and stoats (*Mustela erminae*) that were brought to New Zealand to control the European rabbit in the 1880s (Druett 1983; Lavers and Clapperton 1990). Ferrets were originally released into pasture land of New Zealand, spread into forested areas and were regarded as pests by 1900 (Druett 1983; Lavers and Clapperton 1990). Together with feral cats and rats, predation by these introduced mammals has been the major cause of declines in threatened and endangered species including black stilts (*Himantopus novaezelandiae*) (Murray 1992), yellow-eyed penguins (*Megadyptes antipodes*) (Darby and Seddon 1990), and the royal albatross (*Diomedea epomophora*) (Lavers and Clapperton 1990). Although ferrets prey largely on lagomorphs, diet analysis indicates that ferrets are "opportunistic generalist predators" (Smith et al. 1995). Even when rabbits constituted the largest contribution by weight in the ferrets' diet, there were 18 different bird species including both ground and arboreal nesting birds, identified in gut contents (Smith et al. 1995). In a grassland surrounding a yellow-eyed penguin colony along the southeastern coast of the South Island of New Zealand, birds were identified in 50% of ferret guts and lagomorphs were found 42% of the time (Alterio and Moller 1997). The primary bird species eaten were sooty shearwaters (*Puffinus griseus*) and little blue penguins (*Eudyptula minor*).

A more detailed account of damage caused by ferrets to native wildlife in New Zealand has come from recent studies assessing impacts that rabbit predators may have on threatened species following control of rabbits (Smith et al. 1995; Norbury and Murphy 1996; Norbury and McGlinchy 1996; Alterio and Moller 1996; Norbury et al. 1998). Movement studies indicate that ferrets may expand their home range from 85 ha to 230 ha, or disperse up to 4.3 km from the center of their range when 99% of rabbits are removed from an area (Norbury et al. 1998). The overall effect on prey switching is unknown, but early indications are that in semi-arid tussock grasslands ferrets would shift to increase predation on lizards and invertebrates and in semi-improved pastures, ferrets would increase their predation on birds (Norbury and Murphy 1996).

Concern about threats from new introductions of exotic animals in California originates from wildlife damage resulting from the introduction of other exotic animals like the non-native red fox. The introduction of the non-native red fox into California during the late 1900s (Grinnel et al. 1937) has had negative impacts on several threatened and endangered bird species (Department of Fish and Game 1994). The non-native red fox were escapees or deliberately released from fur farms located in the Central Valley. They spread across the Central Valley and became established in much of the coastal areas in the last two decades from the San Francisco Bay south to San Diego (Burkett and Lewis 1992). It was not until the 1970s that biologists became aware of the damage the non-native red fox was inflicting on the ground nesting birds along the coast (Burkett and Lewis 1992). Non-native red fox have been implicated in population declines of shorebird, marsh bird, mammal, reptile and amphibians in several areas like the El Segundo Dunes, San Francisco Bay National Wildlife Area, Monterey Bay, Seal Beach National Wildlife Refuge and the Ballona Wetlands (Department of Fish and Game 1994).

The red fox has devastated populations of federally listed species such as the light-footed clapper rail (*Rallus longirostris levipes*), California clapper rail (*Rallus longirostris obsoletus*), California Least tern (*Sterna antillarum browni*), and snowy plover (*Charadrius alexandrinus*) (Theylander 1994). These birds are threatened by non-native predators mostly because they nest in close proximity to urban and suburban areas. Many of these areas are devoid of large predators, like the coyote. Just as the non-native red fox can survive in parks, golf courses, coastal marshes and beach areas that are surrounded by urban areas (Burkett and Lewis 1992; Golightly et al. 1994), unwanted or escaped ferrets could potentially survive in these areas and pose additional threats to California's threatened and endangered species. Similarly, offshore islands supporting a diversity of native wildlife could potentially provide habitat for ferrets.

There is a tremendous need for a legislative framework for making decisions in the legalization of exotic species. Protocols should be established to evaluate the cost and benefits each introduction may have on society. In light of the difficulty in assessing costs and benefits from a species introduction, a conservative approach is warranted (Bomford 1991). The damage to wildlife caused by ferrets in New Zealand and the non-native red fox in California should be an alert to the possibility that released ferrets have the potential to threaten endemic species (listed or otherwise) in California. The perceived values of any introduction depends on the interest group that may benefit from such an introduction. Many species of exotic pets continue to be imported, with few regulations in most countries, even though introductions of exotic species have had disastrous impacts (Brown 1989).

Deliberate and accidental introductions are occurring around the globe as a part of human population growth, development and commerce. Future introductions of exotic animals should be based on several criteria (Sjoberg and Hokkanen 1996):

1. It should carry a substantial economic or social benefit to the community.
2. It should not be harmful to humans.
3. The species
   a) is not likely to become established in the wild, or
   b) should not have an adverse ecological impact, or
   c) should be possible to eradicate.
4. If the species does not cause some adverse impact, its benefits should outweigh its actual and potential costs.

Legalization of the ferret in California continues to be a controversial issue with strong emotional arguments for legalization. However, legislation should be based on scientific rather than emotional arguments. There should be some framework with which legislators can make a sound decision on legalization of exotic animals. California legislatures might follow the example of Australia (Bomford 1991) and develop a risk assessment procedure to evaluate the risks and benefits of planned introductions of exotic species. If California is to maintain the largest number of endemic species in the country, it would be prudent to complete such a risk assessment on ferrets prior to their legalization.

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FERAL GOATS IN AUSTRALIA: IMPACTS AND COST OF CONTROL

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ABSTRACT: Feral goats are both a pest and a resource in Australia. They are thought to compete with domestic livestock for food and water and endanger the survival of native flora and fauna. However, there is little quantitative information on the impact of feral goats on agricultural production or conservation values. Their presence on agricultural land is partly tolerated since they can be commercially harvested by mustering or trapping at water points. Where commercial harvesting is not possible, other control techniques must be used. Aerial shooting is the most commonly used technique to remove goats in inaccessible areas, but it is expensive. This paper reviews the status and impacts of feral goats in Australia. It then outlines some cost of control models that predict the cost of controlling goats at different densities using aerial shooting in inaccessible terrain in the semi-arid rangelands of Australia.

KEYWORDS: *Capra hircus*, feral goat, aerial shooting, cost of control, Australia

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INTRODUCTION

This paper is about feral goats in Australia. It moves from a general overview of their history, geographic range, impacts and management to a specific example that describes aerial shooting of goats and some models that predict the cost of controlling goats using this method.

HISTORY

Feral goats (*Capra hircus*) are found world-wide but the highest densities are seen in Australia and New Zealand. Goats were introduced to Australia by European settlers who used them as a source of milk and meat (Mahood 1983). When the demand for these products declined many herds of town goats were released. This gave rise to the establishment of large groups of feral goats in many areas (McKnight 1976). In 1861, cashmere and angora goats were introduced to Australia for their fibre (Lever 1985). Escapees from these herds also added to feral goat populations. These populations have survived and expanded, which has been attributed to several factors, including: 1) lack of predators; 2) high levels of fecundity; 3) freedom from disease; 4) high mobility; and 5) a diverse diet (Henzell 1992).

GEOGRAPHIC RANGE

Approximately 2.6 million feral goats now occur widely in Australia with densities highest in the semi-arid pastoral regions of eastern and western Australia (Wilson et al. 1992; Parkes et al. 1996). They are generalist herbivores (Coblentz 1977) and will eat foliage, twigs, bark, flowers, fruit, roots, plant litter, seeds and fungi (Parkes et al. 1996). In the semi-arid areas of Australia the diet selected by feral goats is variable and largely determined by species availability and seasonal conditions (Harrington 1982). Herbs and grasses are favored when they are growing but once these dry out goats turn to browsing shrubs (Wilson et al. 1975; Harrington 1986). In general, they consume more trees and shrubs than the other large herbivores that share this environment (Dawson et al. 1975). This makes them particularly well suited to some parts of Australia's semi-arid rangelands where shrub densities have increased dramatically in many areas (Cunningham et al. 1992).

The distribution of feral goats in Australia is not as widespread as could be expected given their ability to eat an extremely wide range of food plants. Two factors that may limit their distribution are predation and disease (Parkes et al. 1996). The occurrence of feral goats may be partly influenced by dingo and feral dog predation. Where dingoes are controlled, goat populations have been seen to increase (Parkes et al. 1996). Goats are susceptible to a wide variety of parasites and diseases (Harrington 1982). The ability of diseases to affect goat populations appears to be minimal in dry areas, but their role in wetter areas is unclear. Liverflukes (*Fasciola hepatica*) and a bacterial disease, melioidosis, may be responsible for the absence of feral goats in some wetter areas of Australia (Parkes et al. 1996).

IMPACTS

Feral goats are of concern in Australia for several reasons. Firstly, they are perceived to affect the economic returns of pastoralists by competing with domestic livestock for resources such as food and water. Secondly, goats are considered a threat to conservation. "Competition and land degradation by feral goats" has been listed in the Commonwealth Endangered Species Protection Act 1992 as a threatening process. Finally, feral goats also have the potential to spread and complicate the eradication of exotic diseases, such as foot and mouth disease, due to their widespread abundance and freedom of movement (Wilson et al. 1992).

ENVIRONMENTAL

Feral goats are thought to be involved in the decline of four Australian fauna species. These are the yellow-footed rock-wallaby (*Petrogale xanthopus*) (Lim et al. 1992), the brush-tailed rock-wallaby (*Petrogale pencillata*) (Short and Milkovits 1990), the mallefowl (*Leipoa ocellata*) and the thick-billed Grasswren (*Amytornis textilis*) (Shepherd 1996). The evidence indicating that goats compete with native fauna is largely circumstantial and there is no quantitative data available. It is most likely that the feral goat alone is not responsible for the decline of these species. Other factors, such as fox predation and habitat destruction, may also have a part to play in their decline.

Feral goats are also implicated in the decline of some native Australian plant species. Preliminary work indicates that feral goats do have a significant effect on certain Acacia species (Harrington 1986; Auld 1993; Davies 1995; Maas 1997). On Lord Howe Island goats are thought to have introduced weeds and caused the disappearance of native plant species (Pickard 1976, 1982).

AGRICULTURAL

The economic losses attributed to feral goats in Australian agriculture are estimated to be approximately A$25 million per year. This is made up of losses due to decreased sheep production (A$17.8 million), contingency costs to insure against an exotic disease outbreak (A$6 million) and money spent by government agencies supporting goat control operations (A$1.2 million) (Parkes et al. 1996).

The assumption under-pinning the estimate for lost sheep production is one of substantial dietary overlap and, therefore, competition between sheep and goats. Dietary overlap between sheep and goats can vary enormously (Wilson et al. 1975; Harrington 1986) but will only lead to competition when food is limiting (Choquenot 1992). As yet there is no quantitative evidence that supports the presence of competition between sheep and goats.

PEST OR RESOURCE?

Feral goats provide significant income and employment in the pastoral areas of Australia (Toseland 1992). In 1991 to 1992, the total value of goats and goat products exported from Australia was A$29 million (Ramsay 1994). The great majority of this was derived from feral goats. Harvesting of feral goats benefits many landholders and provides a living for commercial harvesters, abattoir workers, and exporters. Feral goats are also an important game species for recreational hunters and the revenue generated through the sale of sporting goods, vehicles, fuel and other provisions provide an uncalculated source of revenue in rural communities (Parkes et al. 1996). Some 1.2 million goats are harvested annually (Ramsay 1994) which is thought to mitigate some losses and damage attributed to goats. Where commercial harvesting of pests does not achieve densities needed to mitigate impacts then non-commercial control should be considered (Choquenot et al. 1995). It is felt by some that placing an economic value on pests may discourage their control below densities where impacts are mitigated for two reasons: 1) where the attainment of these densities are not commercially viable (Choquenot et al. 1995); or 2) it discourages attempts to achieve high level control or radication (Ramsay 1994). It is for these reasons that the Western Australian state government will make the commercial utilization of feral goats illegal in the year 2000. It is thought that at this time commercial utilization will have no further role to play in the management of feral goats because their densities will have been reduced to levels below which it is commercially viable to harvest them (Feral Goat Eradication Steering Committee 1997).

MANAGEMENT

A range of approaches can be taken to manage feral goats in Australia, with the most common being radication and sustained control. The techniques used to achieve these depend on the habitat the goats occupy and the resources available. Other considerations, such as animal welfare and stakeholder preferences, also come into play.

Eradication

Feral goats have been eradicated from many islands worldwide, including some offshore islands of Australia (Daly and Goriup 1987; Allen and Lee 1995). On mainland Australia, it is very unlikely that all the criteria for successful eradication of feral goats could be met on a national or regional scale (Bomford and O'Brien 1992). This means that with the exception of some offshore islands, the management of feral goats in Australia will mostly be addressed by sustained control. Some agencies in Australia advocate eradication as a goal, while acknowledging that it is not possible. It is felt that this will facilitate the lowest possible densities being achieved by having people strive for "perfection."

Sustained Control

Sustained control requires ongoing commitment but it usually has the desired effect of reducing goat numbers. Ideally goat numbers are reduced to and maintained at a level where their impacts are considered acceptable (target density). As described earlier quantitative data describing the relationship between feral goat density and impacts are not available in Australia. In the absence of adequate impact data a process of trial and error based on the best available data is used for establishing target densities (Parkes 1993).

CONTROL TECHNIQUES

The most common control techniques currently used in Australia are mustering, trapping and aerial shooting. Mustering and trapping preferred because animals can be sold to offset control costs. Aerial shooting is most commonly used in inaccessible areas. Other techniques that are less commonly used or are currently under investigation are ground-based shooting, the Judas goat technique, poisoning, predation by dingoes, fencing and habitat manipulation.

There is no one technique that can be held up as being the best. The approach taken by land managers will depend on local environmental conditions, resources available and their individual circumstances. Often the most efficient and effective approach is to combine two or more techniques.

Mustering

This technique is labor-intensive and generally limited to flat terrain (Harrington 1982). It is most efficient at high goat densities. The two most common methods of mustering used in Australia are: 1) aerial mustering, using helicopters or light aircraft to flush animals out of dense vegetation or inaccessible terrain, followed up by a ground team on bikes that bring the animals into yards; and 2) ground mustering on motor bikes or horseback, usually with the help of dogs, that round up groups of goats and bring them into yards (Parkes et al. 1996).

Trapping

Trapping involves the construction of goat proof fences around a water hole with a number of one way entrances or ramps (Parkes et al. 1996). This technique is effective when goats are obliged to find water during drought and alternative water sources can be fenced off.

Aerial Shooting

In Australia aerial shooting has been successfully used to control a range of vertebrate pest species, including pigs (Saunders and Bryant 1988; Hone 1990), donkeys (Choquenot 1988), water buffalo (Bayliss and Yeomans 1989), and goats (Mahood 1985; Naismith 1992; Maas and Choquenot 1995; Pople et al. 1996). This technique is used to: 1) control inaccessible populations; 2) manage low density populations; and 3) remove survivors from other control campaigns (Parkes et al. 1996). It involves using a helicopter as a shooting platform with light aircraft occasionally acting as "spotters." It is can be an expensive control technique but allows difficult terrain to be covered quickly and gives culling rates far in excess of other methods (Lim et al. 1992).

AN AERIAL SHOOTING CAMPAIGN IN DETAIL

A goat population on Mt Gunderbooka in the semi-arid rangelands of NW New south Wales, Australia was reduced by shooting from a helicopter in September 1992. The outcrop was 75 km^2 in size. Shooting over five days in a Kawasaki/Bell 47 helicopter reduced goat density by 85%.

COST OF CONTROL USING AERIAL SHOOTING

Evaluating the cost of controlling vertebrate populations is essential to understanding the pests role in a production or conservation system (Hone 1994). When the benefits of control (reduced impacts) cannot be easily estimated cost effectiveness analysis is appropriate (Hone 1994). The lack of quantitative information describing the relationship between impacts and feral goat density in Australia make this the appropriate analysis here.

The relationship between cost per animal captured and prevailing animal density can be linear (O'Brien 1985; Brennan et al. 1993) or curvilinear (Bayliss 1986 [as cited in Bayliss and Yeomans 1989]; Choquenot 1988; Parkes 1993; Choquenot and Lukins 1995). In general, the lower the density of prey animals, the greater the cost per kill. This is because the efficiency of helicopter shooting decreases as density is lowered since more time is spent searching for and pursuing animals (Bayliss and Yeomans 1989). Due to this the cost of control increases exponentially with decreasing density (Caughley 1977; Choquenot 1987).

To estimate the cost of a control operation, three things must be determined: 1) the target density that achieves the objectives of the control operation;, 2) the cost of the initial reduction; and 3) the cost of maintaining the target density (Bayliss and Yeomans 1989).

METHODS

To construct a model predicting variation in the cost of removing feral goats as their density was reduced, the relationship between time per kill and density was examined. Time per kill (T) was estimated for each helicopter sortie by dividing the total number of goats killed by the duration of the sortie. Density (D) was taken as that at the beginning of each sortie and was calculated by subtracting the cumulative number of goats shot from previous sorties from the initial population density. This density was estimated from corrected helicopter counts of goat groups conducted prior to the shooting operation. Linear and curvilinear functions were fitted to the relationship between time per kill (T) and density (D).

A linear regression was fitted to examine the possibility that the rate of goat removal had not significantly decreased with declining density and is described by:

$$T = x - bD \tag{1}$$

where: x = time taken to kill the last animal
b = slope of the line

An exponential function was fitted to determine if the rate of killing goats reduced significantly with decreasing density and is described by:

$$T = a + c(\exp(-dD)) \tag{2}$$

where: a = handling time
c+a = time taken to kill the last animal
d = coefficient that determines the efficiency of the relationship

To fit the exponential model the value of a was estimated by averaging T for densities before any appreciable rise in T was apparent. The values for c and d were then derived using an iterative non-linear estimation technique (Statsoft 1995).

Cost of control for both functions was then calculated by multiplying the amount of time (hours) per kill by A$300 for helicopter charter, A$20 for labor and then adding A$2 per kill for ammunition.

PRODUCTIVITY MODEL

A numerical response model (Figure 1) (Maas 1997) describing the population dynamics of the feral goats on the control site was used to develop a productivity model.

Annual recruitment or productivity is determined by multiplying the annual exponential rate of increase (r) predicted by the numerical response model by prevailing density (N) to give:

$$rN = N(-a + c(1 - \exp(-dV))) \tag{3}$$

where: a = the rate of decrease in the absence of food
c = the rate at which a is ameliorated when food is abundant
d = the demographic efficiency of the animals
V = pasture biomass

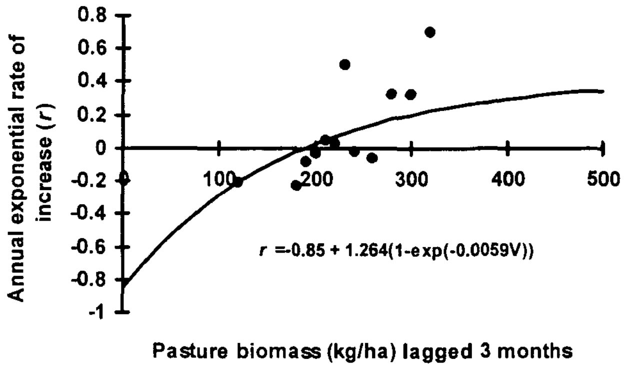

Figure 1. The numerical response of feral goats to pasture biomass lagged three months in a semi-arid environment.

ANALYSIS

The cost of initial reduction and the ongoing costs of control are needed to determine the cost of controlling a feral goat population. The models to predict these will be determined for a hypothetical site 100 km^2 in area with an initial goat density of 25 goats/km^2. This density is similar to the density of animals seen on the outcrop of the study site previous to the experimental reduction.

Cost of the Initial Reduction

The cost of the initial reduction involves determining the time taken to progressively remove each animal until the target density is achieved. This will be determined with the cost of control model which best predicts the time per kill from prevailing density and will, therefore, be described by one of the following functions following Choquenot's (1988) method:

$$\text{Time} = \sum_{i=1}^{F} x - b(D - Di) \tag{4}$$

If the linear function is the best cost of control model or:

$$\text{Time} = \sum_{i=1}^{F} a + c(\exp(-d(D - Di))) \tag{5}$$

If the exponential function best predicts time per kill from density.

For both these functions D is the original population density, F is the target density and Di is the density represented by the progressively reduced population where i is the change in population density equivalent to the number of animals removed. x, b, a, c and d are the same as in equations (1) and (2).

The cost is once again determined by multiplying the time taken per kill by A$300 per hour for helicopter charter, A$20 per hour for labor and then adding A$2 per kill for ammunition.

Cost of Ongoing Control

To determine the cost of maintaining a target density a productivity model is used to predict annual recruitment (rN). These animals must then be removed each year to maintain the target density. The model used to calculate the cost of the initial reduction will be used to determine the cost of maintaining a target density, and so depending on which model was used to calculate the cost of the initial reduction, the cost of ongoing control will be either:

$$\text{Time} = \sum_{i=1}^{F} x - b([Dt + rN] - Di]) \tag{6}$$

If the linear function best describes the cost of control or if the exponential function better predicts cost of control:

$$\text{Time} = \sum_{i=1}^{F} a + c(\exp(-d[(Dt + rN) - Di])) \tag{7}$$

In both these functions Dt is the target density achieved by the initial reduction and rN is annual recruitment as calculated by equation (2). Di and F are the same as for equation (6.3), x,b a, c and d are as for equations (1) and (2). Once again, the cost is calculated by multiplying time by A$300 per hour helicopter charter, A$20 per hour labor and A$2 for ammunition used per animal.

RESULTS

The Cost of Control Model

The exponential model was a better predictor of time per kill from prevailing density than the linear model (Table 1).

Table 1. A comparison of the fit (r^2) and prediction of time to kill the last animal for the two cost of control models fitted to the data.

Model	r^2	p	Time to Kill the Last Animal
Linear	0.24	0.102	2 minutes
Exponential	0.53	0.016	296 minutes

This function predicts that when goat densities are high, handling and search time combined was 0.013 hours per kill or 47 seconds per goat shot. The time taken to kill the last goat predicted by this model is 4 hours and 56 minutes.

The Productivity Model

Using the numerical response productivity can be determined using the function:

$$rN = N[-0.85 + 1.264(1-\exp(-0.0059V))] \quad (8)$$

where: rN = annual productivity of the goat population
N = prevailing goat density
V = pasture biomass (kg/ha)

Cost of the Initial Reduction

Using the exponential function, the cost of the initial reduction down to different densities can be calculated. Figure 2 shows the relationship between target density and the cost of achieving that density on a site 100 km^2 in area with a starting density of 25 goats per km^2. The predicted cost of removing the last goat according to this model is A$290 824.

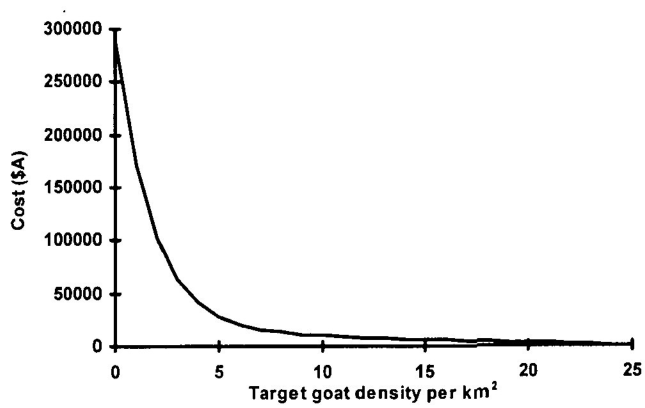

Figure 2. The modeled cost of reducing a population of goats from 25 goats/km^2 to various target densities using aerial shooting.

The Ongoing Cost of Control

Combining the productivity model and the cost of initial reduction model we get a 3-dimensional surface which allows us to predict the cost of maintaining a particular target density under a range of environmental conditions on a site 100 km^2 in area with a starting density of 25 goats/km^2 (Figure 3).

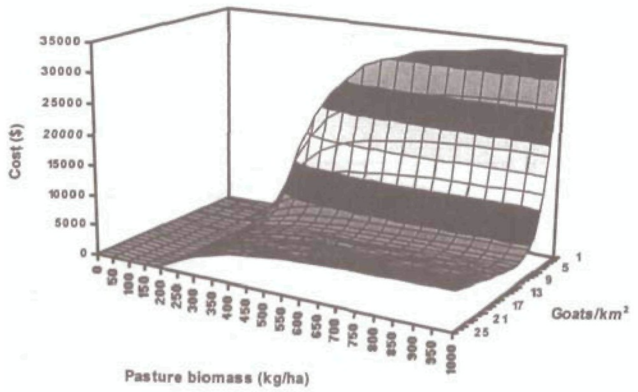

Figure 3. The ongoing costs of maintaining various target densities under different environmental conditions.

DISCUSSION

Cost of Control Models

Only the exponential function had a significant fit to the data with the linear model having a much poorer fit. This demonstrates that the helicopter shooting operation proceeded long enough for the time per kill to become progressively larger as density decreased. The reason for this study having a stronger curvilinear than linear effect of time may be related the change in group size over the course of the shooting campaign. Feral goats have a strong tendency to form groups. These groups may have been larger at the beginning of the control campaign since they had not been selectively culled and had not dispersed due to continued disturbance.

The time taken per kill, and therefore the cost per kill, was very low at high goat densities, but increased markedly when densities approached approximately half the initial density. Shooting became increasingly less cost efficient as goat densities fell below 11/km^2.

Managing Feral Goats in Australia

Feral goats in Australia are most abundant in semi-arid areas where they are both a pest and a resource. Land managers must optimize control in terms of production and/or conservation objectives while keeping in mind control costs and their resource value. Information needed to do this includes an understanding between goat damage and goat density as well as the relationship between goat density and cost of control. This paper presented a cost of control model that was based on the exponential relationship between goat density and costs. In the absence of any information on a relationship between density and damage it is the only tool available to help decide on the optimal level of control in this environment using aerial shooting. Since eradication of feral goats is not possible on Australia's mainland control to a density that is financially sustainable and optimal is prudent until information describing the relationship between impacts and density can further inform the decision making process.

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EVALUATION OF ELECTRONIC FRIGHTENING DEVICES AS WHITE-TAILED DEER DETERRENTS

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ABSTRACT: The authors evaluated the effectiveness of the motion-activated Usonic Sentry (with and without strobe), motion-activated Yard Gard, and Electronic Guard for deterring white-tailed deer (*Odocoileus virginianus*) from preferred feeding areas from February to April 1996. Two four-week experiments were conducted, monitoring deer use (number of intrusions and corn consumption) at eight feeding stations in a 2,200 ha fenced facility in northern Ohio with high deer densities ($\geq 38/km^2$). During these experiments, one of the devices was positioned at each of four sites. The mean ($\pm$ SE, $\underline{n}$ = 4) daily number of deer intrusions at feeding stations during treatment (96.5 $\pm$ 12.6-169.0 $\pm$ 22.0) was similar ($\underline{P} \geq 0.13$) to or greater ($\underline{P} \leq 0.04$) than the mean daily number of deer intrusions during pre- or post-treatment (109.8 $\pm$ 15.6-148.8 $\pm$ 21.4). Corn consumption declined ($\underline{P} \leq 0.05$) only at stations with Usonic Sentrys without strobes for one week. It was concluded that the electronic frightening devices tested were generally ineffective in deterring white-tailed deer from preferred feeding areas.

KEY WORDS: acoustic deterrents, Electronic Guard, frightening devices, *Odocoileus virginianus*, sound, strobe lights, ultrasound, Usonic Sentry, white-tailed deer, wildlife damage management, Yard Gard

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White-tailed deer populations in the United States have increased dramatically in recent years. Ungulate damage to agricultural and ornamental crops is increasing concurrently (Dolbeer et al. 1995). Farmers and agricultural and wildlife agencies have ranked deer as causing more crop damage overall than any other group of wildlife (Conover and Decker 1991; Wywialowski and Beach 1992). Direct removal of deer can reduce the potential for conflict; however, such removals are often controversial, particularly in urban areas. Effective nonlethal techniques are needed to reduce deer damage to agricultural and ornamental crops.

Acoustic frightening devices have been recommended for deterring deer from desired areas (Craven and Hygnstrom 1994); however, previous studies have met with mixed success. Belant et al. (1996) evaluated the effectiveness of propane exploders as white-tailed deer deterrents. They determined that motion-activated exploders were more effective than exploders that fired at regular intervals, probably because deer were unable to habituate to them as readily. Curtis et al. (1995) concluded that the Super Yard Gard ultrasonic device was ineffective as a deer deterrent. However, ultrasound from Super Yard Gards in their study was emitted at regular intervals rather than activated by movements of deer.

The objective of this study was to compare the effectiveness of three electronic frightening devices: motion-activated Usonic Sentry, motion-activated Yard Gard, and Electronic Guard for deterring white-tailed deer from preferred feeding sites. The goal was to develop a technique for reducing deer depredation of agricultural crops, winter livestock food supplies (e.g., stacked hay), and ornamental plantings.

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STUDY AREA

This study was conducted during February to April 1996 at the National Aeronautic and Space Administration Plum Brook Station (PBS), Erie County, Ohio. The 2,200 ha facility is enclosed by a 2.4 m high chain-link fence with barbed-wire outriggers. Habitat within PBS differed from the surrounding agricultural area and consisted of canopy-dogwood (*Cornus* spp.) (39%), grasslands (31%), open woodlands (15%), and mixed hardwood forests (11%) (Rose and Harder 1985). During winter 1995-1996, PBS had an estimated minimum white-tailed deer population of 825 ($\geq 38/km^2$) based on a helicopter facility over the entire facility (P. Ruble, Ohio Div. Wildl.).

METHODS

The authors evaluated the motion-activated Yard Gard (Weitech, Inc., Sisters, Oregon), motion-activated Usonic Sentry (Medlinc of Colorado, Grand Junction), and Electronic Guard (Pocatello Supply Depot, Pocatello, Idaho). All devices were used according to manufacturer specifications. Yard Gards, marketed to deter mammals from desired areas, were evaluated at the medium frequency setting (20 to 28 KHz, 114 dB at 1 m). When activated, the Yard Gard emitted ultrasound for about 7 seconds. Usonic Sentrys were designed to deter mammals by using multiple units to create a perimeter of ultrasound around the area being protected. Usonic Sentrys operated at 23 to 35 KHz with sound pressure of 160 dB at 1 m, and emitted sound for 8 to 18 seconds when activated. During one experiment, a white strobe light (140,000 candlepower [cp], flash rate = 120/min) was connected to the top of each Usonic Sentry. Electronic Guards were equipped with a 1.4 KHz modulating (15 to 20 modulations/minute) siren with 116 dB output at 1 m. Electronic Guards also contained a white strobe light (70,000 cp, flash rate = 60/minute) and were equipped with a photocell such that they were operative during night only. Timers activated the devices for about 7 to 10 seconds at 6 to 7 minute intervals.

Feeding Experiments

During January 1996, eight deer feeding stations were established located ≥ 1 km apart using whole-kernel corn placed in two adjacent 1.2 m long cattle feed troughs. A plastic snow fence (1.5 m high) was erected on three sides of a 5 x 5 m area such that feed troughs were located inside the fenced areas about 1 m from the back. Corn was added to feed troughs as necessary to maintain a constant food supply and the weight of corn added was recorded (Belant et al. 1997). An infrared monitoring device (TrailMasterR, Goodson and Assoc., Inc., Lenexa, Kansas) was installed 60 cm above ground at each opening to record the number of deer intrusions and avoid recording nontarget species (e.g., raccoons [*Procyon lotor*], fox squirrels [*Sciurus niger*]).

Experiment 1. Four feeding stations were selected randomly to each receive a Usonic Sentry without strobe. The remaining four stations received a Yard Gard. Each device was attached to a post about 1.2 m above ground and centrally located within the fenced area on the back side. Motion sensors were positioned such that any deer that approached the feeding stations would activate the device 1 to 3 m prior to being detected by the infrared device.

Using the TrailMasters, the daily number of deer intrusions at each feeding station was monitored until the number of intrusions did not increase for one week. The experiment consisted of a one-week pretreatment (beginning February 9), two-week treatment, and one-week post-treatment period. The appearance of each feeding station was identical among periods except that frightening devices were activated during treatment only.

The authors divided the daily values recorded by the infrared monitors by two to determine the number of deer entering each feeding station. The mean daily number of intrusions/week for each station was calculated. Analysis of variance (ANOVA) with repeated measures (weeks) (SAS Inst., Inc. 1988) was used to compare the mean number of deer intrusions and mean amount of corn consumed (kg) by week for each device. Data were log-transformed prior to analyses because of heterogeneity of variances (Zar 1984). If main effects were significant ($P \leq 0.05$), Tukey tests were used to determine which means differed.

Experiment 2. This experiment was initiated one week after the conclusion of Experiment 1. Electronic Guards and Usonic Sentrys with strobes were placed at the sites which previously contained Usonic Sentrys without strobes and Yard Gards, respectively.

The experimental design and statistical analyses were similar to those described for Experiment 1. However, to determine whether the strobe lights modified deer use of feeding stations, the percent of movements that occurred during night (sunset to sunrise) were calculated, and the authors analyzed these movements across weeks by frightening device using repeated-measures ANOVA on log-transformed data.

RESULTS

Experiment 1

There were no differences in the mean daily number of deer intrusions among weeks for the Yard Gard (96.5 ± 12.6-109.8 ± 15.6) ($F = 0.51$; 3,9 df; $P = 0.6852$) or Usonic Sentry (105.3 ± 18.6-132.0 ± 23.6) ($F = 2.48$; 3,9 df; $P = 0.1272$) (Figure 1). There was a difference in corn consumption among weeks, however, for the Yard Gard and Usonic Sentry ($F = 26.31$-26.98; 3,9 df; $P < 0.0001$). Corn consumption decreased ($P < 0.05$) from pre-treatment (4.8 ± 1.0 kg) to week 1 treatment (1.5 ± 0.9) for stations with Usonic Sentrys, but not with Yard Gards (6.5 ± 1.4-2.3 ± 0.8) ($P > 0.05$). For both devices, the amount of corn consumed then increased (≥17.3 ± 2.5) ($P < 0.05$) during week 2 treatment and remained constant ($P > 0.05$) through post-treatment.

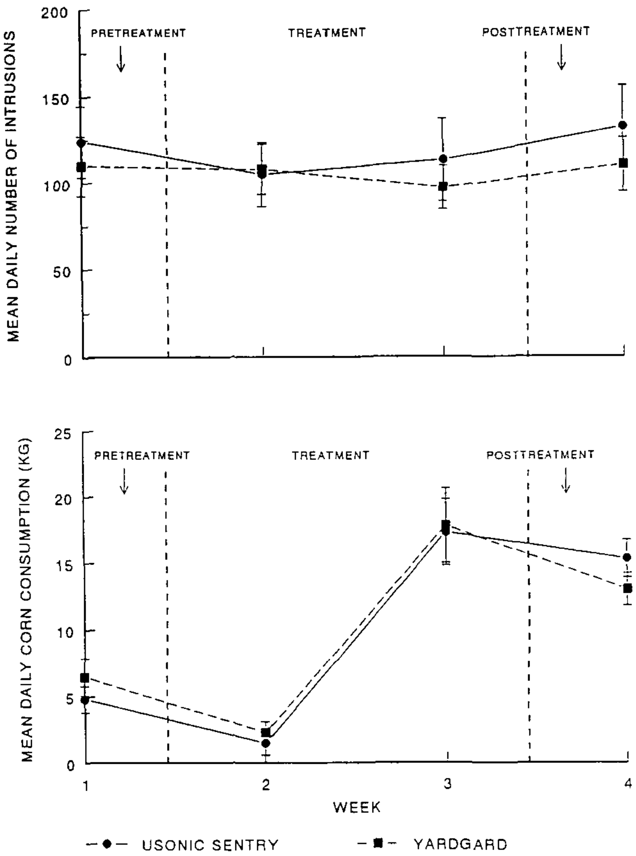

Figure 1. Mean daily number of white-tailed deer intrusions and mean daily corn consumption at sites with Usonic Sentry or Yard Gard by week, Plum Brook Station, Erie County, Ohio, February to March 1996. Capped vertical lines represent 1 standard error.

Experiment 2

Mean daily number of deer intrusions differed among weeks for the Usonic Sentry with strobe ($F = 4.52$; 3,9 df; $P = 0.0340$) and the Electronic Guard ($F = 4.11$; 3,9 df; $P = 0.0430$) (Figure 2). For the Usonic Sentry and Electronic Guard, the respective mean daily number of intrusions increased from pre-treatment (124.0 ± 13.5 and 148.8 ± 21.4) through treatment (140.0 ± 12.6 and 169.0 ± 22.0) then declined during post-treatment (103.5 ± 9.8 and 131.0 ± 13.9). The mean percent of intrusions during night at feeding stations with Usonic Sentrys increased ($\underline{F}$ = 4.79; 3,9 df; $\underline{P}$ = 0.0292) from pre-treatment through treatment. For stations with Electronic Guards, the mean percent of intrusions at night was similar ($\underline{F}$ = 2.71; 3,9 df; $\underline{P}$ = 0.1077) among weeks. Corn consumption differed ($\underline{F}$ = 3.87-5.18; 3,9 df; $\underline{P}$ ≤ 0.0497) among weeks at stations with Usonic Sentrys or Electronic Guards. Corn consumption generally was greater during treatment than during pre-treatment or post-treatment periods.

DISCUSSION

The initial (one week) reduction in corn consumption after Usonic Sentrys (without strobes) were activated was probably because deer were affected by the novel stimulus. Nonetheless, habituation to devices occurred rapidly (< 1 week) for deer intrusions into feeding sites. In addition, strobe lights on Usonic Sentrys did not further reduce deer use of sites or alter movements by time of day. Motion-activated Yard Gards were ineffective in reducing deer movements and corn consumption at feeding stations, even during week 1 of treatment. Curtis et al. (1995) reported systematically-activated Super Yard Gard ultrasonic devices were ineffective in deterring white-tailed deer from bait sites. The increase in consumption of corn at all feeding stations observed during the first experiment was likely a consequence of a 15 cm snowfall during week 2 treatment which reduced relative availability of alternate food. Also, this study was conducted when alternate food was least available (winter and early spring); thus, overall effectiveness of the devices tested may have been reduced relative to other times of year.

The Electronic Guard was developed originally to reduce coyote predation on livestock (Linhart 1984; Linhart et al. 1992). Livestock producers and fruit growers have reportedly also used Electronic Guards to reduce damage to haystacks and orchards caused by deer and elk (U.S. Dep. Agric. 1995). Data from this study do not support reductions in deer use of preferred feeding areas. The only other quantified study evaluating sonic devices as deer deterrents involved propane exploders (Belant et al. 1996). Belant et al. (1996) determined that motion-activated propane exploders were more effective (up to six weeks) than exploders fired at regular intervals (effective for about two days), probably because deer were unable to habituate to them as readily.

Because none of the sonic or ultrasonic devices tested reduced deer use of feeding sites for > 1 week, it is unlikely these devices used alone would deter deer from other preferred food (e.g., agricultural crops, ornamental trees and shrubs). The lack of negative reinforcement associated with the frightening devices tested probably allowed deer to habituate more rapidly than if additional negative stimuli (e.g., pyrotechnics or shooting with a gun to frighten or kill) were provided. As with other vertebrate deterrents, incorporation of multiple techniques in an integrated approach is generally more effective than use of individual techniques.

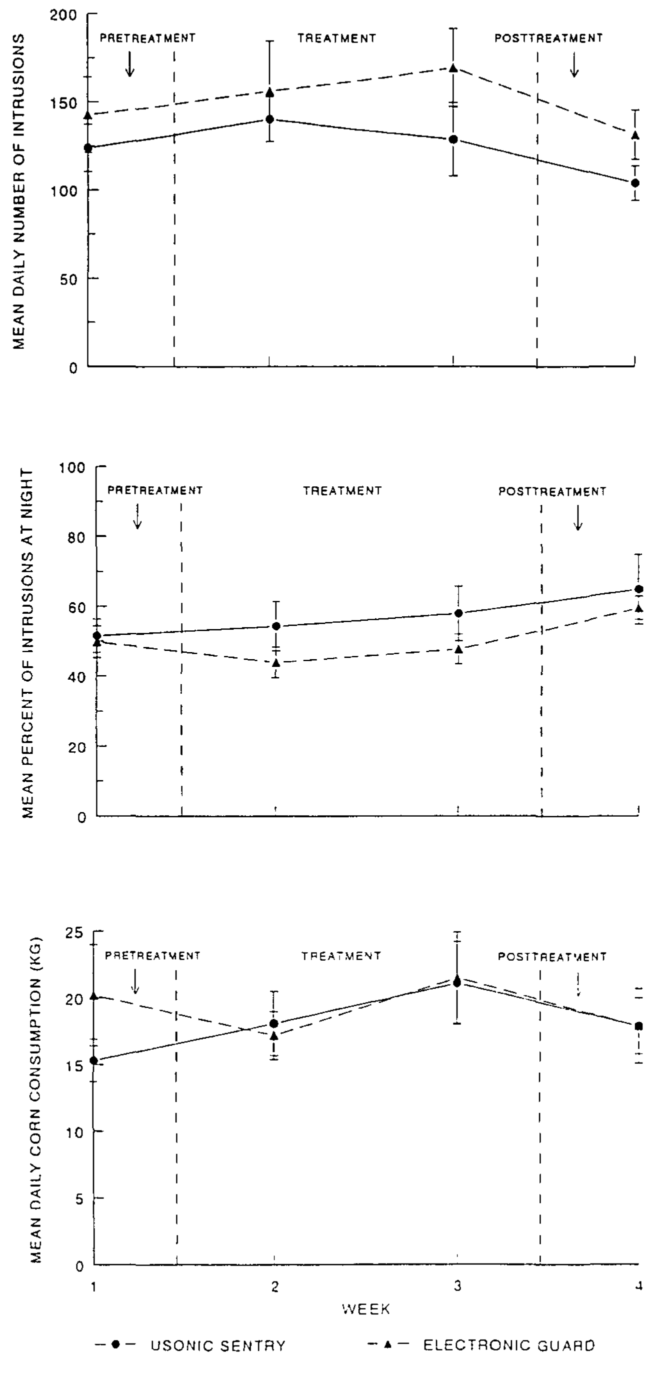

Figure 2. Mean daily number of white-tailed deer intrusions, mean percent of intrusions at night (sunset to sunrise), and mean daily corn consumption at sites with Usonic Sentry (with strobe) or Electronic Guard by week, Plum Brook Station, Erie County, Ohio, March to April 1996. Capped vertical lines represent 1 standard error.

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THE IMPACT OF TIMBER MANAGEMENT ON THE PHYTOCHEMICALS ASSOCIATED WITH BLACK BEAR DAMAGE

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ABSTRACT: Black bears forage on Douglas-fir vascular tissue in the spring, and this behavior can be severely detrimental to the health and economic value of a timber stand. Foraging is selective in that not all stands are damaged and, within a stand, one tree may be stripped while its neighbor is ignored or minimally sampled. A series of studies was conducted to assess whether bear selectivity is affected by chemical constituents within vascular tissue, and whether these constituents are affected by silvicultural practices. The results are interpreted to identify forest practices that may alleviate damage, or at least predict where damage is most likely to occur.

KEY WORDS: Black bear, damage, fertilization, foraging, forest resources, genetics, pruning, sugars, terpenes, thinning

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INTRODUCTION

Black bears (*Ursus americanus*) commonly forage on Douglas-fir (*Pseudotsuga menziesii*) trees during the spring (Ziegltrum and Nolte 1996). Vascular tissues from Douglas-fir are staples in the diet of some bears (Noble 1993). Bears generally forage on the lower bole of trees, ranging from 15 to 30 years of age, by removing the bark with their claws and then scraping the vascular tissue from the heartwood with their incisors. Any age tree, however, is vulnerable to bear damage and bears occasionally strip an entire tree. Damage within a stand can be extensive as a single bear may peel bark from 50 to 70 trees per day (Schmidt and Gourley 1992).

The damage inflicted by bears is extremely detrimental to the health and economic value of a timber stand. Complete girdling is lethal, while partial girdling reduces growth rates and provides avenues for subsequent insect and disease infestations (Kanaskie et al. 1990). The severity of timber loss is compounded because bears tend to select the most vigorous trees within the most productive stands, and often damage occurs after stand improvements (e.g., thinning, fertilizer) have been implemented (Mason and Adams 1989; Nelson 1989; Kanaskie et al. 1990; Schmidt and Gourley 1992). The problem is exacerbated because of the extended time (20 plus years) necessary for a timber stand to return to its pre-damaged state.

Foraging bears appear to be selective in their choice of trees. Several trees within a stand may be stripped while their adjacent neighbors are ignored or minimally sampled. Bear damage also occurs more frequently in certain types of timber stands. Thinned stands tend to be more vulnerable than higher density stands (Mason and Adams 1989; Kanaskie et al. 1990; Schmidt and Gourley 1992). Depredation also has been reported to increase after fertilization (Nelson 1989). The apparent dietary criteria of bears is to select for vigorous trees.

This paper summarizes a series of studies conducted to assess whether bear selectivity is affected by chemical constituents within vascular tissue, and the impact of forest management practices on these constituents.

RELATIONSHIP OF CHEMICAL CONSTITUENTS AND BEAR FORAGING

The authors related damage to the concentration of sugars and terpenes found in the vascular tissue of Douglas-fir. Sugars were chosen because of their high concentration in vascular tissue (Radwan 1969). Animals derive energy or protein from the plants they ingest (Robbins 1983). There is little or no protein in Douglas-fir vascular tissue (Radwan 1969). Therefore, the benefit bears glean from Douglas-fir must be obtained from the energetic sugars. Other omnivores, such as rats, demonstrate a preference for foods containing sugars (Jacobs et al. 1978).

Terpenes were investigated because high concentrations are present in conifers (Kimball et al. 1995), and they deter foraging by other species. Pine oil repels snowshoe hares (*Lepus americanus*) and voles (*Microtus townsendii*) (Bell and Harestad 1987) and causes avoidance behavior in pocket gophers (*Geomys bursarius*) (Epple et al. 1996). Several terpene compounds in balsam poplar deter feeding by snowshoe hares (Reichardt et al. 1990). The concentration of certain monoterpenes also is a predictor of tassel-eared squirrel (*Sciurus aberti*) feeding on ponderosa pine (*Pinus ponderosa*) (Farentinos et al. 1981).

Chemical Constituents

The initial study correlated chemical constituents in Douglas-fir trees to the extent of damage inflicted by black bears (Kimball et al. 1998b). Stands of Douglas-fir were monitored for bear foraging activity during the spring of 1994 and 1995. Stands with recent (less than five days) damage to at least 15 trees were included in the study. Only Douglas-fir trees with areas of removed bark and incisor marks on the remaining vascular tissue were sampled. Trees with no evident foraging marks were not sampled since it could not be ascertained whether they had been encountered by a foraging bear.

The surface area or removed bark and diameter at breast height (DBH) were determined for each damaged tree. Vascular tissue was collected by removing two 40 x 10 cm patches of bark on opposite sides of the tree and scraping the vascular tissue (phloem and xylem oleoresin located immediately beneath the cork cambium) into a freezer bag. Samples were collected at breast height (1.5 m).

The freezer bag and contents were immediately placed in liquid nitrogen for two to five minutes. The samples were kept frozen until homogenized with a mallet and divided into two portions. One portion was maintained frozen until analyzed for terpenes, while the other was lyophilized and analyzed for carbohydrates. Chemical analyses for terpenes (Kimball et al. 1995) and carbohydrates (Kimball et al. 1998b) are described elsewhere. Vascular tissue density was determined as the mass of vascular tissue per 800 cm^2 sample area.

Douglas-fir vascular tissue was analyzed for 20 different terpenes. Typically, the most prevalent terpene compounds were: alpha-pinene, beta-pinene, sabinene, limonene, 3-carene, myrcene, camphene, terpinolene, and bornyl acetate (in order of abundance). The concentration of alpha-pinene was approximately ten times that of the other major terpenes. Galactose, glucose, xylose, fructose, sucrose, coniferin, and an unknown compound were present in all extracts analyzed for sugars.

For statistical analysis, the variables were: concentration of hydrocarbon monoterpenes, concentration of oxygenated monoterpenes, concentration of sesquiterpenes, concentration of major carbohydrates, concentration of coniferin, vascular tissue density, and DBH.

Multiple regression yielded significant models for four of the six sites (Table 1). The coefficients of determination (R^2) obtained from the significant models indicate that the variables used account for half to three-quarters of the variation observed in the removed bark data. Diagnostic evaluation of the data detected no violations of the assumptions of linear regression.

The results indicated that tree selection by bears is probably related to sugars and terpenes. Bears select for sugars and select against terpenes. It is assumed that the amount of bark removed from a tree was directly related to bear preference for that tree. Trees with minimal (ca. 20 cm^2) bark removed during foraging were frequently found adjacent to trees with extensive (up to 15,500 cm^2) bark damage. The area of bark removed was the only quantitative evidence of preference present. Therefore, trees with minimal bark damage were regarded as less preferred trees. While highly preferred trees were those with extensive bark removal. The correlative nature of this study, however, did not establish that the chemical constituents were causally related to preference.

Bear Bioassays

The field bioassay was designed to establish causative effects on foraging preference due to sugars and terpenes (Kimball et al. 1998b). Free ranging black bears were offered the choice of four prepared test diets varying in carbohydrate and terpene concentrations (Table 2). Diet delivery was based on the supplemental feeding program of the Washington Forest Protection Association (WFPA; Ziegltrum and Nolte 1996).

Ten sites with a history of bear activity were selected for the study. At each site, four feeders were placed in close proximity (10 cm) to each other in a square configuration with the feeder openings oriented toward a central focus. A pre-bait treatment was conducted to entice bears to the stations and to ensure adequate activity. The pre-bait treatment consisted of filling each feeder with the supplemental feed employed by the WFPA feeding program and hanging a beaver carcass in a tree near the feeding stations. Sites were monitored for activity every third or fourth day. Two sites were eliminated from the study because of low bear activity.

Following two weeks of bear activity at a site, the WFPA feed was removed and the four tests diets were randomly placed in the feeders. Sites were monitored every three or four days for a total of seven monitoring intervals. Mean daily intake was calculated for each interval.

Bears selected diets to regulate their intake of carbohydrates and terpenes (Figure 1). The free ranging bears in this study preferred the low terpene diets to the high terpene diets at the high sugar concentration. Bears also preferred the high sugar/high terpene diet to the low sugar/high terpene diet. Generally, sugars produce positive feedbacks from intake while terpenes can induce negative consequences. Thus, bears appear to have learned to forage in a manner that maximizes sugar intake while minimizing terpene intake.

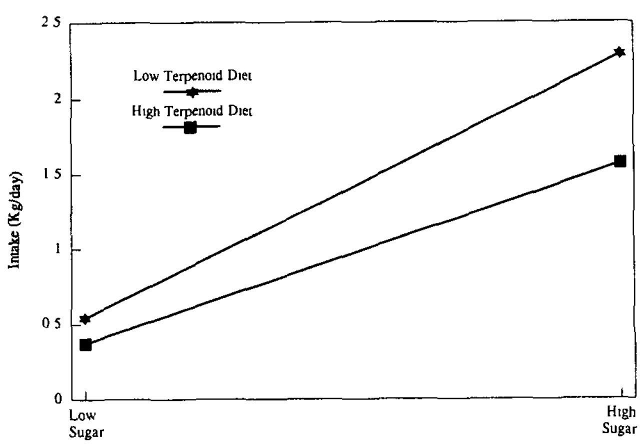

Figure 1. Mean daily intake of the four test diets used in the bioassay to assess bear responses to varying concentrations of sugars and terpenes (Kimball et al. 1998b).

Table 1. Statistics from multiple regression analyses where area of removed bark was the response and the predictors were the chemical concentrations of hydrocarbon monoterpenes, oxygenated monoterpenes, sesquiterpenes, carbohydrates, and coniferin, and the physical measurements tree diameter (DBH) and vascular tissue density (Kimball et al. 1998b).

	Site					
Statistics	McCleary	Kelso	Cowlitz	Rasberry	Silver Falls	Molalla
p	0.80	0.05	0.06	0.04	0.60	0.03
R^2	0.14	0.44	0.78	0.63	0.44	0.55

Table 2. Concentrations of carbohydrates and terpenes in diets offered to black bears during field bioassays.

Diets	Carbohydrates	Terpenes
High Sugar/High Terpene	8.5%	263 ppm
High Sugar/Low Terpene	8.0%	86 ppm
Low Sugar/High Terpene	5.0%	290 ppm
Low Sugar/Low Terpene	5.0%	44 ppm

IMPACT OF FOREST MANAGEMENT PRACTICES

The next series of studies investigated the impact of forest management practices on the chemical constituents identified as affecting bear behavior. The authors wanted to determine whether their foraging model could help to identify forest practices that may alleviate damage, or at least to predict where damage is most likely to occur. Stand density was selected because it is generally understood that bear damage is likely to increase in a thinned stand (Mason and Adams 1989; Kanaskie et al. 1990; Schmidt and Gourley 1992). Thus, investigating changes in chemical constituents relative to stand density provided an opportunity to assess whether the predictor of damage compared favorably with common knowledge. Similarly, the authors wanted to ascertain whether their model matched favorably with what was known regarding an increase in bear damage post urea fertilization (Nelson 1989).

Bear response to pruned trees was largely unknown. After determining the effect pruning had on vascular tissue concentrations of sugars and terpenes, the authors were fortunate to have the opportunity to evaluate bear damage within stands where every other tree had been pruned. Finally, chemical concentrations among progeny test families were evaluated to determine the potential of selecting for a tree less palatable to wildlife while maintaining desirable qualities, such as productivity.

Thinning and Fertilization

For this study, it was hypothesized that bear preference for trees in thinned or fertilized stands was mediated by a higher concentration of vascular sugars and/or a lower terpene concentrations relative to trees in higher density or unfertilized stands (Kimball et al. 1998d).

The study was conducted on Stand Management Cooperative (SMC) installations in western Washington and Oregon. SMC installations were established in healthy Douglas-fir stands planted between 1974 and 1984. The cooperative initiated silvicultural treatments between 1987 and 1992 to investigate the impacts of current management practices on growth and wood production (Stand Management Cooperative 1993). The SMC employed pre-commercial thinning to yield three stand density levels. High density plots (850 to 1,400 stems per hectare; sph) were obtained by not thinning, while other plots were thinned to a mid-density level (400 to 700 sph), and yet other plots were thinned to a low density level (250 to 325 sph). Trees on fertilized and unfertilized plots representing each of these density levels were investiaged. Urea (46-0-0) had been hand applied (224 kg/ha) 1, 2, 3, or 4 years prior to sampling.

Growth parameters were measured and tissue samples were collected from eight trees within each plot. Sample collection was as previously described, except a single 80 cm x 10 cm patch was taken from the east side of the tree. Samples were stored, and the chemical assays to determine sugar and terpene concentrations were conducted as described by Kimball et al. (1995) and Kimball et al. (1998b).

Tree diameter (a measure of cumulative growth; Table 3) and vascular tissue mass (a measure of current growth; Figure 2) were increased by thinning. Furthermore, thinning significantly increased the sugar concentration of the vascular tissue (Table 3) while having only a minor impact on the terpene concentration. Thus, the net effect of thinning was an increase in the sugar to terpene ratio of the vascular tissue.

Table 3. Mean tree diameters ($p = 0.007$) and vascular tissue sugar concentration ($p = 0.02$) by tree density level (values followed by the same letter are not significantly different; Kimball et al. 1998d).

Density Level	Tree Diameter	Total Sugar Concentration
Low (250 to 325 sph)	20.4 cm (A)	3.19% (A)
Mid (400 to 700 sph)	18.9 cm (B)	3.03% (B)
High (850 to 1,400 sph)	18.1 cm (B)	2.98% (B)

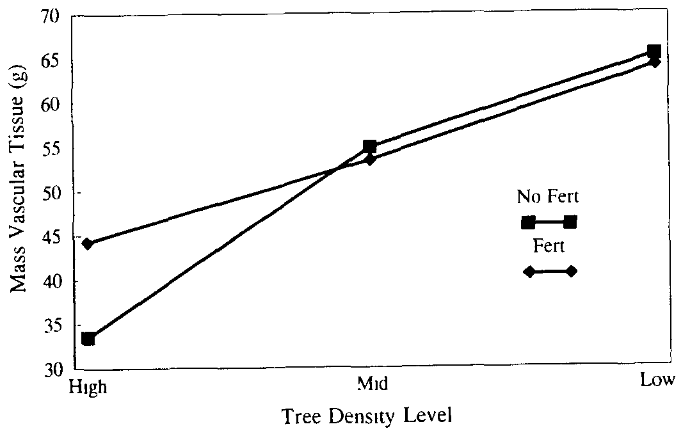

Figure 2. Effects of tree density and fertilization on vascular tissue mass (Kimball et al. 1998d).

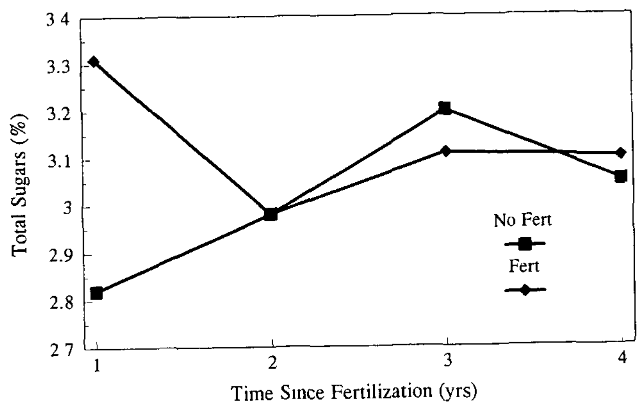

Figure 3. Effects of urea fertilization and time since fertilization on total sugars (Kimball et al. 1998d).

Fertilization had a positive effect on DBH. Sugar concentration was impacted only the first year after fertilizing (Figure 3), and there was no impact on terpenes. Fertilization had a positive effect on tissue mass in high density stands, but did not have an effect at mid or low density levels (Figure 2). Though trees were not sampled the year fertilizer was applied, it is likely that fertilization effects were apparent the year of treatment. Uptake of nitrogen by conifers can be rapid (Carlyle 1995). The observed increase in tree diameter in the absence of increased vascular tissue mass suggests a growth spurt in the same year the treatment was applied. There was no difference in sugars between trees on fertilized and unfertilized plots after the first year.

These results provide credence to the hypothesis that the concentration of chemical constituents within forage can be used to predict the occurrence of bear foraging. Bear preference for trees in thinned stands may be partially attributed to higher vascular tissue sugar concentrations. Bears also benefit by foraging where the available mass of vascular tissue is greater, most likely providing more return per bite.

Bear preference for fertilized stands also can be explained, at least in part, by the chemical constituents of the vascular tissues. Nelson (1989) indicated that bear damage in fertilized stands was most frequent in the years immediately after fertilization. Results suggest that bears prefer urea fertilized trees the spring after treatment, and this preference probably last through the next year.

Pruning

Pruning is typically performed to increase wood quality (O'Hara 1991), but it also can negatively impact tree growth (Langstrom and Hellqvist 1991). The authors hypothesized that pruning also would impact the chemistry of the vascular tissue, perhaps rendering the trees less desirable to bears. This study was conducted to assess the affect of pruning on the concentrations of sugars and terpenes within the vascular tissue of Douglas-fir (Kimball et al 1998c). Subsequent to the chemical assays, the authors were fortunate to be able to test their prediction of bear foraging within stands where every other tree had been pruned.

The impact of live crown pruning on the allocation of sugars and terpenes in the vascular tissue was investigated on three Oregon Department of Forestry (ODF) sites. At each of these sites, two years prior to tissue sampling all the live and dead whorls were removed to a height of 5.0 m. This resulted in the removal of approximately 40% of the live crown.

Vascular tissue samples were collected as previously described, except samples were collected from three heights along the stem of the tree. First, a lower bole sample was collected at 1.0 m from the east side of a pruned tree. The mid bole sample was located at the point of the first whorl of live branches. The upper bole sample was taken half way between the mid bole sample and the top of the tree. Samples were then collected at the same locations from an adjacent unpruned tree, paired because of similarities in height and diameter. Eight pairs of pruned and unpruned trees were sampled at each site. All samples were analyzed for sugars and terpenes as previously described.

Pruning significantly impacted growth and vascular chemistry throughout the bole of the tree (Table 4). Growth was suppressed in pruned trees, particularly in the lower bole. Vascular tissue mass and sugar concentrations also were reduced in pruned trees. Terpene concentrations were highest in the lower bole. Sesquiterpenes were the only group of terpenes to be affected by pruning. Sesquiterpene concentration in pruned trees was 0.37 ppm and 0.15 ppm in unpruned trees. Thus, pruning decreased the sugar to terpene ratio. The authors would predict, therefore, that pruned trees would be less desirable to bears than unpruned trees, particularly in the lower bole which is the part of the tree most likely to be encountered.

Bear preference for unpruned trees was demonstrated in a survey of bear damage on a 21 ha ODF site which had been subjected to the same pruning treatment as described above. Trees with existing bear damage at the time of treatment were marked by painting the damaged area. Treatment was applied four years prior to this survey. Bear damage was evaluated by recording the species, treatment (pruned or unpruned), bear damage since treatment (yes or no), and pre-treatment damage (paint or no paint) for all trees (1,646) that occurred within five, 15 m wide transects systematically placed across the site.

Species encountered in the survey were Douglas-fir (77%), Western hemlock (22%), and Sitka spruce (1%; *Picea sitchensis*). Presence of Sitka spruce was inadequate for statistical analysis. Pre-treatment damage occurred independent of treatment. Therefore, there was not a worker bias to select for a precondition (damaged or undamaged) while pruning. Damage since treatment was significantly impacted by pruning. The calculated odds ratio suggests that unpruned Douglas-fir trees were four times more likely to be damaged than pruned trees. Similarly, unpruned Western hemlock were three times more likely to be damaged than pruned trees. Providing further confidence in the hypothesis that bear foraging choices reflect chemical constituents.

Genetic Selection

Douglas-fir genetics has been previously related to mammalian herbivory. Foliar concentrations of monoterpenes in certain Douglas-fir clones are thought to render them less palatable to deer (Radwan and Ellis 1975). Similarly, snowshoe hare avoidance of Douglas-fir is under genetic control (Dimock 1976). This study was conducted to determine whether terpenes previously identified to affect bear foraging behavior are subject to genetic control (Kimball et al. 1998a).

The impact of progeny selection on the allocation of terpenes in the vascular tissue was investigated in a cooperative study with the USDA Forest Service and the Northwest Tree Improvement Cooperative. Samples were collected from six known genetic families of Douglas-fir at five different progeny test sites. These sites were originally established 28 year ago to rank families for growth and wood quality traits. Test families for this study were selected to provide comparisons among original growth rankings (taken at 15 years of age) from slow to fast growth. The DBH and mass of vascular tissue in the 800 cm^2 sampling area were determined as a measure of cumulative and current growth for each tree. Vascular tissue samples were collected and analyzed for terpenes according to the procedures of Kimball et al. (1995).

Tree diameter was consistent with the original rankings (Table 5). Mass of vascular tissue (current growth) was similar among families. Similarities in current growth may have been because canopy closure had induced self pruning causing a decrease in vascular tissue growth in the lower bole of the tree (Kimball et al. 1998c).

Chemical assays indicated that the amount of terpenes is not necessarily correlated with growth. Principle components analysis assigned related terpenes to five terpene groups, based on the correlation matrix. All terpenes within a group were positively correlated with each other. Terpenes in two of these groups were subject to site x family interactions. Some families had high concentrations at one site, but contained low concentrations at another site. In a third group of terpenes the concentrations of some individual terpenes were higher in faster growing families than in those

Table 4. Relative presence of vascular tissue chemical constituents of pruned and unpruned Douglas-fir trees at three bole heights ($\underline{P}$ <0.05; Kimball et al. 1998c).

Chemical Constituent	Treatment	Bole Height
Vascular tissue mass	Unpruned > Pruned	Mid = High > Low
Hydrocarbon Monoterpenes	Unpruned = Pruned	Low > Mid = High
Oxygenated Monoterpenes	Unpruned = Pruned	Low > Mid = High
Sesquiterpenes	Pruned > Unpruned	Low > Mid = High
Total Carbohydrates	Unpruned > Pruned	Low = Mid = High

families with less growth potential. Interestingly, the terpenes in group 2 are in general the most prominent terpenes present in Douglas-fir vascular tissue. This relationship suggests that it may be possible to select for trees that are less palatable to bears without sacrificing growth potential.

SUMMARY

Tree selection by black bears is at least in part related to the concentrations of sugars and terpenes present in vascular tissue. Bears foraging in environments that offer choices are likely to select for trees which offer the highest sugar to terpene ratio. This research suggests that the sugar to terpene ratio of Douglas-fir vascular tissue can be reduced by cultivating trees at higher stand densities and by pruning live crown cover. Urea fertilization affects the ratio only the initial couple of seasons after application. While sugar concentrations were affected by environmental factors, terpene concentrations can be increased through genetic selection. It appears plausible to select for trees containing greater concentrations of terpenes without affecting positive attributes such as productivity.

Table 5. Current mean DBH and original rank (15 years) of six genetic families of Douglas-fir at five different progeny test sites (DBH values followed by the same letter are not significantly different (Kimball et al. 1998a).

Family	Original Rank	Current DBH
21	4	25.25 A
90	1	24.39 AB
20	10	23.16 BC
29	13	23.11 BC
30	22	22.12 C
376	18	22.10 C

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TRENDS IN MOUNTAIN LION DEPREDATION AND PUBLIC SAFETY INCIDENTS IN CALIFORNIA

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ABSTRACT: Mountain lions (*Puma concolor*) are widely distributed and have apparently expanded their range and increased in abundance in California since the early 1970s. Conflicts between mountain lions and humans have increased during this period. Trends in verified mountain lion damage to livestock and pets are reported for the 26-year period 1972 to 1997. Confirmed mountain lion attacks on humans are summarized for the period 1890 to 1997. This information was analyzed by county, and related to mountain lion habitat suitability, livestock distribution, and human population trends. Health and physical characteristics of a sample of 417 mountain lions were also analyzed for the period 1990 to 1996. Public policy related to mountain lions is discussed with emphasis on trends in conflicts with humans and management implications.

KEY WORDS: mountain lion, depredation

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INTRODUCTION

The mountain lion (*Puma concolor*) is widely distributed in California over approximately 62% of the state (253,828 sq. km). Of this area, it is estimated that 170,486 sq. km is moderately to highly suitable habitat (Torres et al. 1996). There have been numerous changes in state law intended to guide management of this controversial species. Despite these measures, conflicts between humans and mountain lions have increased in number and sensitivity.

This paper reviews recent trends, and updates information on mountain lion depredation and threats to public safety in California, provided by Mansfield and Torres (1994). The objectives in this review were to: 1) provide verified data for mountain lion damage to property and threats to public safety; and 2) discuss factors associated with these trends and implications for management of conflicts involving mountain lions. The authors hope sharing this information will provide insight and encourage an increased understanding of complex relationships between factors influencing mountain lion-human interactions in California.

POLICY AND PUBLIC OPINION

Management of mountain lions in California has a long and diverse history. The initial state law designated the species a bountied predator, and it was in effect from 1907 to 1963. During that 57-year period, records indicate that 12,461 mountain lions were killed (Mansfield and Weaver 1989). From 1963 to 1969, lions were managed as nongame and take was not regulated or systematically recorded. In 1969, the Legislature designated mountain lions as game mammals and required hunting licenses and tags for taking them. During the period 1970 to February 1972, records indicate 4,953 tags were issued and 118 mountain lions were killed. In 1972, the Legislature enacted a moratorium on hunting, required a depredation permit for taking lions causing damage, and directed the California Department of Fish and Game to determine the status of mountain lions and to make recommendations for their management.

In response, the Department initiated field studies in the early 1970s, including radiotelemetry which provided the first empirical estimates of home range size and local densities to complement refined estimates of statewide distribution (Sitton and Weaver 1977). It also implemented a depredation permit procedure which has been relatively consistently applied from 1972 until the present. The relatively few changes involved minor variation in the length of time for which a permit was valid, distance from the damage site a lion could be pursued and taken, and prohibiting the use of a foot snare for taking a lion after June 1990.

The mountain lion was again classified a game mammal in 1986 when the last extension of the hunting moratorium laws expired. This abrupt change in status resulted in the Department of Fish and Game recommending, and the Fish and Game Commission immediately adopting, a regulation continuing depredation permits. The Department also recommended deferring a decision on hunting lions until the available information related to the statewide and regional mountain lion populations could be analyzed and alternatives evaluated. In 1987, the Commission requested, and the Department provided, a biologically conservative proposal for the regulated take by licensed hunters of up to 190 lions distributed over four zones, excluding southern California. This hunting proposal was challenged in court during 1987 and 1988, with an appeal pending in 1990 when a ballot initiative (Proposition 117) was approved by 52% of the voters. This change in law designated the mountain lion a "specially protected mammal," prohibited hunting, and further restricted the take of lions causing damage to property. Proposition 117 also increased the penalties for illegally taking lions, authorized the Department to take lions which were a perceived threat to public safety, and directed the expenditure of $30 million of existing public funds annually for 30 years to specific activities, including acquiring habitat for mountain lions and other wildlife.

Recreational hunting of mountain lions has been prohibited for 25 years in California, and circumstantial evidence indicates lions have become more numerous and expanded their range over that period (Torres et al. 1996). Concurrent with that trend, the human population in the state has increased from approximately 19 million in 1970 to over 32 million in 1998. The influence of this expanding human population, on both the landscape and the nature of conflicts with mountain lions, has been great. Public opinion regarding lions ranges from speculating that the increasing statewide population poses a serious threat to human lives, populations of prey and property, including livestock and pets, to believing that increases in the human population and activity in lion habitat are solely responsible for conflicts. Both of these extreme views involve the potential errors of generalizing statewide and assuming that changes in human and lion demographics operate independently. The available information reflecting mountain lion and human activity provides a basis for evaluating some relationships in factors which may contribute to conflicts between lions and humans in California.

DATA AND TRENDS

Depredation

The policy, regulations, and data collection procedures for mountain lion depredation have been fairly consistent since 1972. They include issuing a permit on request of the property owner in each case where the Department verifies a mountain lion was responsible. There are strict guidelines which are intended to restrict take to the offending lion. Information is recorded on the date, county, sex of lion taken, type of property damaged, and other factors involved in each case. The carcass of any lion taken must be provided to the Department. During the period 1972 to 1997, depredation incidents by lions ranged from 4 in 1972 to 323 in 1995. The number of mountain lions taken ranged from 1 in 1972 to 121 in 1994 (Figure 1).

A detailed multi-variate analysis of these data through 1995 by Torres et al. (1996) determined that there were several significant direct relationships, including those between domestic sheep depredation and the amount of suitable lion habitat by county and pet depredation and average annual new house development by county. It appears that increasing domestic sheep depredation may reflect increases in the distribution and abundance of mountain lions. Counties with increasing trends in pet depredation are the same areas where public safety problems have increased which may reflect increases in human activity in lion habitat.

Domestic sheep have accounted for over half of the total in terms of type of property damaged annually over the last 25 years (Figure 2). When the data were analyzed separately for the periods 1972 to 1984 and 1985 to 1995, there was a significant increase in the number of permits issued for damage to pets and a significant decrease in the number of permits issued for damage to cattle (Torres et al. 1996). The highest concentrations of depredation permits were issued in the north coastal (Humboldt and Mendocino counties), northwestern (Lake, Shasta, Siskiyou, and Trinity counties), and central Sierra Nevada (Amador, Calaveras, El Dorado, Kern, Mono, Tulare, and Tuolumne counties) regions of the state.

It appears that pet depredations are associated with high human populations. The highest concentrations of pet depredation was in the south coastal (Los Angeles, Orange, and San Diego counties) and northern and southern Sierra Nevada (Alpine, Butte, Inyo, Lassen, Madera, and Tulare counties) regions. Mountain lion attacks on pets appeared to be inversely related to total depredation by county.

The sex ratio of lions associated with total livestock depredation had a male bias which varied from 60% for cattle to 75% for horses. Lions involved in pet depredation had a female bias with only 45% male, and this difference was significant. Within the limitations of age estimates obtained during necropsies, about two-thirds of the lions associated with livestock and pet depredations were adults (>2 years old) and one-third were subadults.

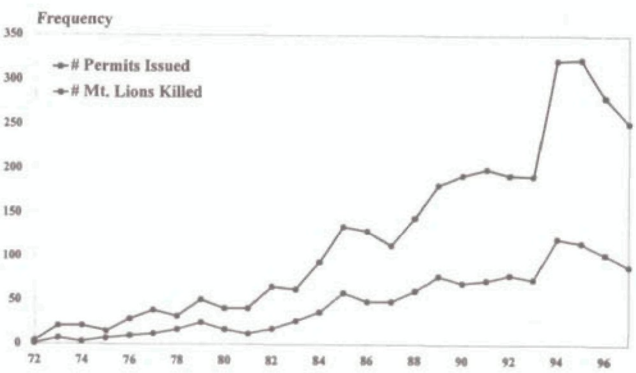

Figure 1. Summary of confirmed mountain lion depredation incidents in California, 1972 to 1977.

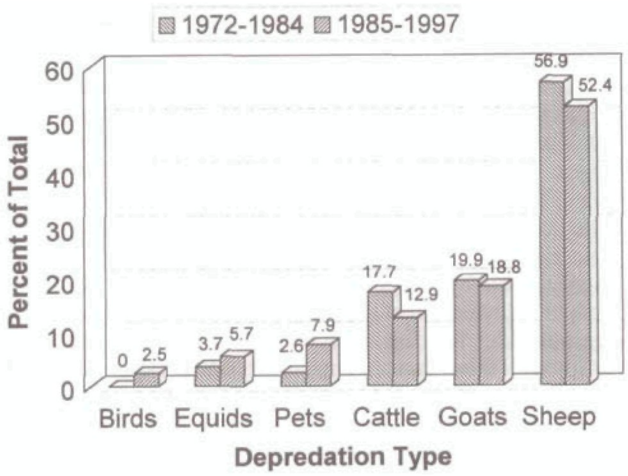

Figure 2. Type of mountain lion depredation (% of total) by time period (1972 to 1984, 1985 to 1995) in California.

Public Safety

There have been 10 verified cases of mountain lions attacking humans in California from 1890 to the present, eight of them from 1986 to 1995. They involved 12 victims and five fatalities. The sex ratio of lions associated with public safety problems had a slight female bias at 46% male and was similar to that for pet depredation. Dates, locations, and additional information on these incidents are summarized in Table 1. Because of the low number of public safety incidents, potential statistical analysis is limited. However, Torres et al. (1996) speculated that the deaths of two adult women from mountain lion attacks in 1994 resulted in an increase in public attention to, and concern for, mountain attacks on livestock, pets, and humans. They concluded that the increase in requests for depredation permits in 1994 and 1995 was likely due to those events, and that pet depredation may be related to potential public safety problem areas.

Mountain Lion Physical Condition

The health and condition of a sample of 417 mountain lions necropsied during 1990 to 1996 were generally assessed. Lions were classified as being in either "fair to excellent" or "poor" condition based on weight, amount of body fat, coat condition, and general appearance. The condition of mountain lions killed on depredation permits was compared to the condition of lions dying from other causes during the same period. Those causes included take for public safety, roadkills, disease, and various injuries.

During the period 1990 to 1996, 97% of the lions killed on depredation permits were classified as being in fair to excellent condition, and 100% were in that condition during four of those years. In contrast, 75% of the mountain lions dying from other causes were in fair to excellent condition. Only eight of the sample of 309 lions taken on depredation permits during this period were in poor condition. Of these lions in poor condition, four were old (>7 years), three were young (<1 year old), and one had damaged teeth. The poor condition of these lions appeared to be due to starvation as a result of their inability to catch prey rather than disease.

DISCUSSION

There is strong circumstantial evidence that mountain lions have increased in numbers and expanded their range in California during the last 25 years. Concurrently, there is speculation by a segment of the public that prohibiting hunting during that period is responsible for the increase. The human population in California has increased by over 40% during that period, and there is speculation by a segment of the public that expanding urban development into mountain lion habitat is responsible for the increase in lion-human conflicts. Although these factors appear to contribute to the trends in conflicts between lions and humans, they do not explain the trends statewide. These generalizations fail to consider the regional variation in important factors including habitat quality, prey availability and human impacts on the landscape.

Despite these contrasting views and opinions, most of the public recognizes mountain lions as a valuable part of California's wildlife diversity. There appears to be a common desire to focus potential management on practical and biologically sound solutions that ensure long-term viability of mountain lion populations while promoting public safety and minimizing property damage. However, the state's mountain lion management policy has been primarily influenced by polarized advocates insisting that activities be narrowly focused.

The California Department of Fish and Game has developed management goals for mountain lions which include: 1) maintaining viable mountain lion populations; 2) minimizing conflicts related to public safety, property damage, and other wildlife; 3) protecting important habitats; 4) recognizing their ecological role and value; 5) monitoring populations and conducting research; and 6) improving public awareness. These goals set the stage for solutions based on a sound biological principles and public support. Meeting these goals will require funding for long-term population monitoring and research which has not been available.

CONCLUSIONS

Mountain lion activity reflected as verified damage to livestock and pets tends to support the conclusion that lions have increased in number and expanded their range in California during the last 25 years. Depredation on domestic sheep is directly related to the amount of suitable lion habitat at the local and regional levels. Pet depredation by mountain lions is increasing as a proportion of total depredation, and it may be a useful indicator of lion activity in proximity to humans. Since lion attacks on humans occur so infrequently, statistical analyses with other covariates are not practical.

Managing mountain lions in California will continue to be a challenge. Polarized public opinion and political pressure by narrowly focused advocates have limited the options for adaptive management and applied research which may help reduce conflicts between mountain lions and humans. There is a need to manage lions in conjunction with, not in isolation from, concerns for public safety, protecting property, and other wildlife interactions.

ACKNOWLEDGMENTS

The authors are grateful for the assistance and advice provided by Mr. Steve Torres for both general review and statistical analysis of mountain lion and human activity data; and Ms. Amy Brinkhaus for summarizing data and preparing figures.

Table 1. Verified mountain lion attacks on humans in California, 1890 to 1995.

				Victim		Mountain Lion	
Date	Location	County	Type	Age	Sex	Age	Sex
June 1890	Quartz Valley	Siskiyou	Fatal	7	M		F
July 1909	Morgan Hill	Santa Clara	Fatal[b] Fatal[b]	10 22	M F		
March 1986	Caspers County Park	Orange	Nonfatal	5	F	2	M
October 1986	Caspers County Park	Orange	Nonfatal	6	M		
March 1992	Gaviota State Beach	Santa Barbara	Nonfatal	9	M	A	M
September 1993	Cuyamaca Rancho State Park	San Diego	Nonfatal	10	F	1-2	F
April 1994	Auburn State Rec. Area	El Dorado	Fatal	40	F	2-3	F
August 1994	Dos Rios (remote)	Mendocino	Nonfatal[c] Nonfatal[c]	50s 50s	M F	2	F
December 1994	Cuyamaca Rancho State Park	San Diego	Fatal	56	F	A	M
March 1995	Angeles National Forest	Los Angeles	Nonfatal	28	M	A	F

[a]Ages recorded in years. Adult mountain lion ($\geq$3 years) are noted as A.
[b]Fatalities diagnosed due to rabies.
[c]Mountain lion confirmed to have rabies.
[d]Adapted from Torres et al. 1996.

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NORTH DAKOTA'S COST-SHARE PROGRAM FOR GUARD ANIMALS

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ABSTRACT: Beginning in July 1991, the North Dakota Game and Fish Department authorized the use of funds in a cost-share program to assist farmers and ranchers with the implementation of nonlethal methods to protect livestock. Fund expenditures are administered and approved by the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, North Dakota program. The program provides a 50:50 cost-share up to a maximum of $150 per purchase of nonlethal items for the protection of livestock from predation. During the six year period from July 1991 to July 1997, the program has cost-shared dogs, donkeys, electronic guards, and llamas. The Great Pyrenees dog breed was the method most frequently selected.

KEY WORDS: guard dogs, Great Pyrenees, Akbash, Maremma, llama, donkey, nonlethal

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INTRODUCTION

In the 17 western states the economic impact of predation on sheep exceeds $50 million annually (Connolly 1992). Methods used by livestock producers to reduce or eliminate predation consist of both of lethal and nonlethal practices. Lethal practices are usually implemented by professionals with experience in wildlife damage management because of federal and state regulations and because special skills are required. Nonlethal techniques are usually implemented by livestock producers and consist of preventive methods such as habitat modification, animal husbandry, and modifying animal behavior.

Animal husbandry practices generally involve modifying the level of care or attention given to livestock and include, but are not limited to: guard animals, herders, shed lambing, carcass removal, and fencing. Habitat modification alters habitats to attract or repel certain wildlife species or to separate livestock from predators. Modifying animal behavior refers to tactics used to alter the behavior of wildlife and reduce predation (e.g., fences, propane exploders, pyrotechnics, guard animals, or electronic guards).

Beginning in 1991, Wildlife Services (WS) entered into a cooperative reimbursable agreement with the North Dakota Game and Fish Department to reduce the loss of domestic livestock to coyotes (*Canis latrans*) and red fox (*Vulpes vulpes*). The agreement provided two years of funding for cost-sharing of aerial hunting, and the cost-sharing of providing technical assistance and education to farmers and ranchers. Technical assistance included electronic scare devices, guarding animals, propane exploders, and other mutually agreed upon expenditures. The agreement has been renewed three times since its inception.

BACKGROUND

North Dakota encompasses approximately 45 million acres with the primary land use being agriculture. During 1995, North Dakota agriculture generated almost $3 billion in cash receipts (North Dakota Agriculture Statistics Service 1995). On less than 2 million acres of public grazing land during 1991, gross livestock sales generated $71.5 million (Bangsrud and Leistritz 1992). Consequently, livestock production plays an important role in North Dakota's economy.

Predation on livestock economically impacts producers. Predation on cattle occurs periodically throughout the year, whereas sheep are killed year-round. Consequently, individual sheep producers may suffer greater economic losses from predators than do cattle producers. The 1994 National Agriculture Statistics Service (1995) figures for North Dakota reported 4,000 sheep and lambs killed by predators. Coyotes were reported as the largest cause of predator loss accounting for 82% of the sheep and 89% of the lambs.

North Dakota averaged 164,667 sheep during 1993 to 1995 (North Dakota Agriculture Statistics Service 1995). Of the predation verified by WS employees in North Dakota during 1993, 1994, and 1995, coyote predation accounted for 96%, 95%, and 95% of the lambs and 100%, 64%, and 82% of the sheep, respectively.

METHODS

When a WS employee is called to investigate a possible incident of predation on livestock, he/she uses the Animal Damage Control Decision Model (Slate et al. 1992) to assess the problem, evaluate the currently employed methods, formulate a strategy, provide assistance, and monitor the results. WS assistance can be technical assistance or direct control or a combination of both methods.

As part of the technical assistance program, WS offers the producer an opportunity to participate in the cost-share program. The cooperative program provides funding on a 50:50 (WS:producer) basis with a maximum expenditure of $150 per purchase. For example, if the assistance cost $100, the producer would receive $50 or if the assistance costs $400, the producer would receive a maximum of $150. For the producers to claim a reimbursement, they have to submit to WS a form describing the item they purchased and a signed copy of the bill of sale. This paper pertains only to the data collected from the "Guarding Animal Cost Share Application."

RESULTS

During the six years the program has been implemented, sheep producers purchased 63 guard animals. Three producers purchased guard dogs to protect goats and one producer purchased a donkey (*Equus assinus*) to protect his horses and cattle. Eighteen producers did not report the type of livestock to be protected.

During the 1992-1993 biennium, 47 producers participated in the program purchasing 2 llamas (*Lama glama*), 9 donkeys, and 42 guard dogs. Producers reported purchasing burros and donkeys, but the names are used interchangeably (Green 1989b). For this paper the authors will use the name donkey. The average purchase price for a donkey was $236 with a range of $75 to $500. The price for each guard llama was $500. Great Pyrenees dogs were the breed of choice accounting for 95% of the selection and averaged $137 with a range of $47 to $300. One Akbash dog ($250) and one Maremma dog ($250) were also purchased.

During the 1994-1995 biennium, 22 producers participated in the program purchasing 0 llamas, 8 donkeys, and 19 guard dogs. The average purchase price for donkeys was $226 with a range of $50 to $600. Great Pyrenees dogs were again the breed of choice accounting for 95% of the selection and averaged $172 with a range of $55 to $300. A Maremma dog was also purchased for $300.

During the 1996-1997 biennium, 16 producers participated in the program purchasing 3 llamas, 4 donkeys, and 14 guard dogs. The average purchase price for donkeys was $194 with a range of $75 to $250. Llamas averaged $417 and had a range of $350 to $500. Great Pyrenees again outnumbered other breeds of guard dogs with 64% of the selection and averaged $191 with a range of $100 to $275. Akbash dog was the second most selected dog breed (29%) and averaged $537 with a range of $450 to $750. One Maremma dog was also purchased for $150.

Not all producers reported the size of their sheep herds. Of the 54 producers that used guard dogs to protect their sheep, the average size of sheep herd was 234 head (range 4 to 1,500). Eighty-eight percent of the guard dogs selected to protect sheep were Great Pyrenees. The average size of the sheep herd protected by Great Pyrenees was 234 head (n=48, range 4 to 1,500). The average size of the sheep herd protected by Akbash dogs was 271 head (n=5, range 200 to 500) and only one Maremma dog was reported as protecting sheep (45 head). The average size of the sheep herd protected by llamas was 512 head (n=5, range 87 to 1500) and the average size of the sheep herd protected by donkeys was 405 head (n=17, range 44 to 2,500).

Ages varied among the guard animals purchased. Great Pyrenees (n=48) ranged in age from 1.5 to 72 months with 75% less than 6 months (Figure 1). The median age for Great Pyrenees was 3 months and the mode was 2 months. The average age for Akbash dogs (n=5) was 7.4 months and ranged from 5 to 11 months. Maremma dogs (n=3) were aged 2, 3.5, and 8 months. Guard donkeys (n=21) ages averaged 45 months and ranged from 2 to 144 months (Figure 2). The average age for llamas (n=5) was 29.6 months with a range of 13 to 48 months.

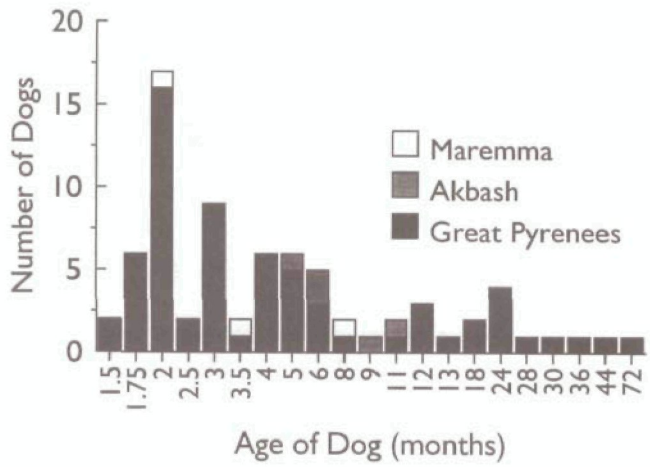

Figure 1. The age of guard dogs selected in the cost-share program in North Dakota during 1991 to 1997.

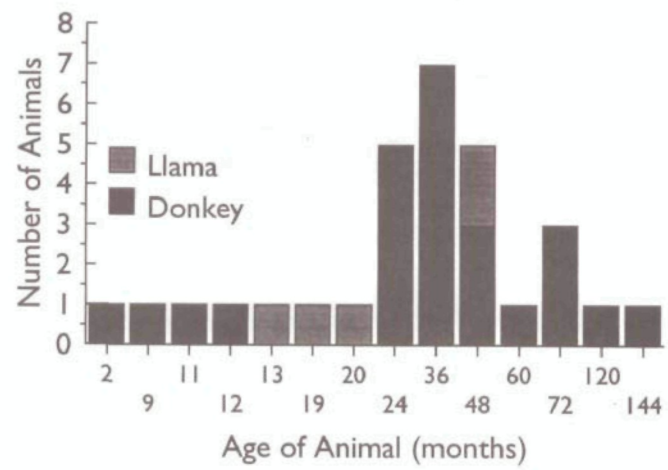

Figure 2. The age of guard llamas and donkeys selected in the cost-share program in North Dakota during 1991 to 1997.

Training of the guard animal varied from none to extensive on-the-job training. There was some confusion on the survey as to what type of training was to be reported. Some producers reported what education they or the seller had for training guard animals. Thirty-three Great Pyrenees (49%) were listed as having no training, while 25 (37%) had been raised with sheep (Figure 3). Eleven donkeys (52%) had some experience protecting flocks of sheep or goats and four individuals (19%) had been raised with sheep since birth (Figure 4). Sixty percent (3) of the llamas had some experience working with sheep.

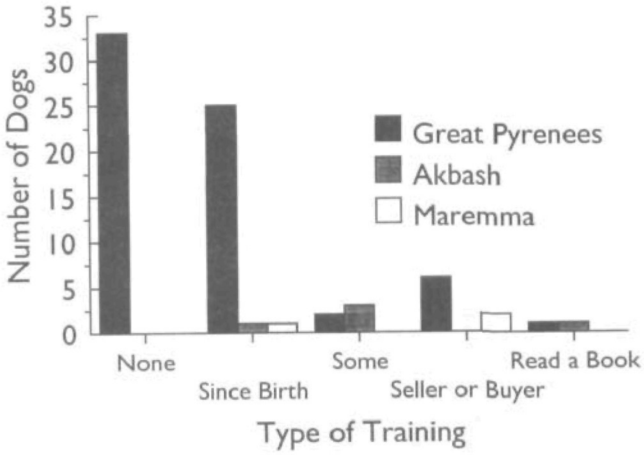

Figure 3. The type of training that individual guard dogs had when they were purchased by the cost-share program in North Dakota during 1991 to 1997.

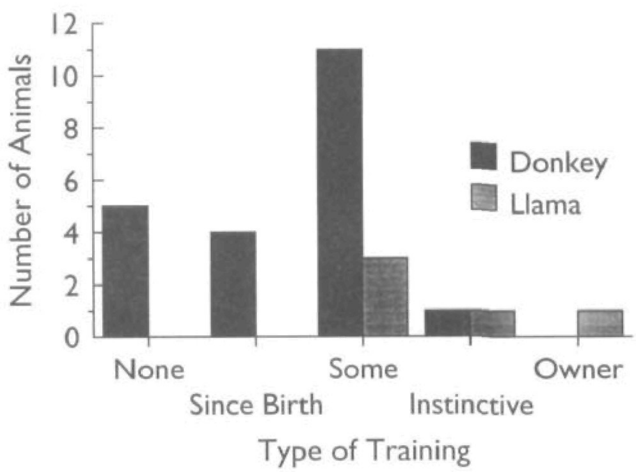

Figure 4. The type of training that individual guard llamas and donkeys had when they were purchased by the cost-share program in North Dakota during 1991 to 1997.

DISCUSSION

The use of guard animals enables producers to use grazing areas that were under utilized due to the presence of predators (Green and Woodruff 1996). Producers also become more self-reliant and gain other potential benefits such as: 1) reduced predation; 2) reduced labor; 3) improved potential for profit; 4) increased flock size; 5) protection of family members and other property; and 6) peace of mind (Green and Woodruff 1996).

Factors influencing the selection of guard animals include: cost, experience of the producer, size of herd, characteristics of the species or breed, maintenance of the species or breed, accessibility to breeders, time available for training, whether the guard animal is trained, and the availability of guard animals.

Nationally, 38% (± 1.4% SE) of sheep producers used guard dogs, 11% (± 0.9% SE) used guard donkeys, and 6% (± 0.6% SE) used guard llamas (U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Veterinary Services 1996). The national figures are comparable to North Dakota WS data for producers using WS where 34% (n=134) of the sheep producers and 30% (n=6) of the goat producers used guard dogs, 12.7% (n=50) of sheep producers and 10% (n=2) of the goat producers used guard donkeys, and 2.3% (n=9) of the sheep producers and 5% (n=1) of the goat producers used guard llamas (North Dakota Wildlife Services unpubl. data). But when given the opportunity to cost-share guard animals, livestock producers chose guard dogs (74%) over guard donkeys (21%) and guard llamas (5%).

Guard dogs have been used in North Dakota since the mid-1970s (Pfeifer and Goos 1982). During a 1981 survey, 96% of the guard dogs used in North Dakota were Great Pyrenees, and 4% were Komondor dogs (Pfeifer and Goos 1982). During the 1990s, Great Pyrenees (89%) are still the dog of preference, with Akbash dogs (6%) and Maremmas (4%) also being selected.

North Dakota livestock producers have stated their preference for Great Pyrenees because they mature at an earlier age, are less possessive and more mobile, easier to breed and to train (Pfeifer and Goos 1982). Additional studies have also stated that Great Pyrenees mature at an earlier age, are less aggressive towards livestock and family members, and are culled less often than other breeds (Green and Woodruff 1988; Green 1989a).

During the 1970s, the average cost of guard dogs in North Dakota was $590 (Pfeifer and Goos 1982). During the past 20 years, the average price of guard dogs in North Dakota has dropped to a low of $176 with individual guard dogs costing as little as $47.50. A reduction in purchase price could be attributed to the increased use of guard dogs in the United States and a subsequent supply of puppies from additional breeders.

Based on this survey, Akbash were at least twice as expensive to purchase as Great Pyrenees. The authors speculate that the reason producers were willing to pay more for a certain breed is similar to Colorado sheep producers who stated that Akbash were significantly more effective than Great Pyrenees (Andelt and Hopper 1997). They also rated Akbash as being more aggressive, more active, faster, and more intelligent than Great Pyrenees.

During the 1990s, the survey showed that 75% of Akbash had some form of training or experience prior to being purchased, whereas only 40% of Great Pyrenees and 33% of Maremmas had some form of training or experience. This is a change from the 1970s when ranchers were buying dogs with no experience for guard dog work (Pfeiffer and Goos 1982).

The age of guard dogs was not noted in Pfeiffer and Goos' (1982) 1981 survey. They did note that producers had the best luck with pups purchased at six weeks of age and raised with lambs. During this survey over 95% of the dogs and puppies purchased were more than seven weeks of age. Seventy-five percent of the producers showed a preference for purchasing puppies by buying animals that were less than six months old.

The average sheep herd size protected by guard dogs during the 1970s was 590 animals (Pfeifer and Goos 1982). Twenty years later, the average size of sheep herds protected by guard dogs has dropped more than 50% to 234 animals. The average size of sheep herds (405 head) protected by donkeys in North Dakota was almost twice the size of the average sheep or goat herd size (213 head) guarded by donkeys in Texas (Walton and Field 1989) and dogs in North Dakota. The average sheep herd size guarded by llamas was more than twice the sheep herd size guarded by dogs in this survey. The authors suggest caution when comparing the numbers provided on llamas and donkeys due to the small sample sizes.

Franklin (1993) stated that guard llamas which were gelded cost $700 to $800 and intact males were $100 cheaper. The average purchase price for llamas bought in the cost-share program was $450 with a maximum cost of $500. The authors suggest that the pricing of llamas, as with the pricing of guard dogs, follows the typical economic theory of supply and demand.

In a study conducted by Iowa State University, producers had good success with llamas averaging two years of age and no prior experience guarding sheep (Franklin 1993). The llamas purchased during this program were more than one year of age with the maximum age being four years. Fifty percent of the llamas purchased in the cost-share program had some experience as a guard animal.

The purchase price for donkeys in North Dakota ranged from $50 to $600 with an average price of $235.71. The North Dakota purchase price was higher than the price paid for donkeys in Texas which ranged from $75 to $150 dollars (Wilbanks 1995). The low purchase price of $50 was for an immature donkey purchased from a private seller and the high range was for an animal having experience with sheep. Seventy-one percent of the donkeys purchased in the cost-share program had experience with sheep or goats. The increased amount paid for a guard donkey in North Dakota vs Texas suggests that producers were willing to reduce their risk on an unproven feral animal by paying more for an experienced animal.

The cost-share program entered its fourth biennium on July 1, 1997. The program continues to offer producers a means to be more self reliant and use a wide range of techniques to manage predation.

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NON-LETHAL PREDATION CONTROL BY U.S. SHEEP PRODUCERS

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ABSTRACT: The USDA National Agricultural Statistics Service (NASS) surveyed U.S. sheep producers to determine the kinds of non-lethal (NL) predator control measures they used in 1994. An analysis of responses from 8,451 sheep producers showed that 34% of the nation's sheep producers used fencing, 25% used husbandry, 20% used guard animals, 4% used frightening tactics, 0.3% used aversion, and 3% used other methods. Because NL methods tended to be used more in large sheep operations than on small farms, the percentages of sheep protected by each NL control method were higher than the percentages of sheep producers using the method. Approximately 33% of all sheep in the U.S. were protected by fencing, 40% by husbandry, 39% by guard animals, 12% by frightening tactics, 2% by aversion, and 5% by other methods. Overall, 55% of U.S. sheep producers used one or more NL predator control methods in 1974, and 70% of the nation's sheep were protected by one or more NL methods.

KEY WORDS: Predators, predation management, sheep, non-lethal methods, fencing, husbandry, guard animals, frightening tactics, aversion

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INTRODUCTION

The U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) and Animal and Plant Health Inspection Service (APHIS) have cooperated on many surveys of wildlife damage to agriculture. Several national surveys have estimated sheep and goat (NASS 1991, 1995a,b) or cattle and calf (NASS 1992, 1996a) losses to predators and other causes. These studies have shown that the coyote is the most important predator of sheep and lambs in the U.S.

In January 1995, NASS asked sheep producers to report their predator control practices and expenditures during 1994. The results showed that fencing and husbandry practices were the leading non-lethal (NL) control measures used in that year (NASS 1995a). This brief summary did not estimate the percent of sheep producers who used each control method or the percent of sheep protected by specific methods, nor did it compare NL predation management practices on sheep operations of different sizes. The authors undertook additional analyses to obtain these estimates. The findings are summarized in this paper.

METHODS

NASS and its cooperating state agricultural statistics services surveyed a random sample of U.S. agricultural producers by mail, telephone, and face-to-face personal interviews in January 1995. All sheep and lamb producers, regardless of size, had a chance to be included in the survey; however, Alaska was excluded. Large producers were sampled more heavily than small operations. Producer responses were voluntary. Survey procedures and results were presented in detail by NASS (1995a,b).

Sheep producers who participated in this survey were asked which of the following NL predator control methods or groups of methods were used on their farms or ranches during 1994:

a. Husbandry practices (herders, corrals, carrion removal, pasture selection and grazing variation, habitat changes, season and location of lambing, etc.)
b. Frightening tactics (lights, bells, radios, propane exploders, strobe lights, sirens, etc.)
c. Aversion (repellents, aversive conditioning, etc.)
d. Fencing (net-wire, electric, etc.)
e. Guard animals (guard dogs, donkeys, llamas, etc.)
f. Other (specify)
g. No NL predator controls used

Sheep producers' responses (n = 10,798) to this survey were obtained, together with sampling weights, electronically from NASS. Weights were recalculated to account for 807 nonrespondents. Respondents (n = 531) who had no sheep on January 1, 1995 were dropped from further analysis. In addition, it was found that the records for 1,009 respondents were unusable because they failed to indicate whether or not respondents used NL control measures. The analysis was based on the remaining 8,451 responses.

It was hypothesized that the use of NL predation control methods would vary with the size of sheep operations, large producers being more likely than small operations to use such methods. To elucidate this, respondents were sorted into flock size classes based on the number of sheep and lambs on each farm on January 1, 1995. Four size classes were defined: class 1 = 1 to 49 sheep; class 2 = 50 to 199 sheep; class 3 = 200 to 999 sheep; and class 4 = 1,000 or more sheep.

Two weighted analyses were performed—one to estimate the percentages of sheep producers who used each method and another to estimate the percent of sheep protected by each method—using SUDAAN software (Software for the Statistical Analysis of Correlated Data, Research Triangle Institute Release 7.00, April 1996).

Percentages of respondents (unweighted data) and sheep producers (weighted) who used each NL method, or used no NL method, were estimated by state for each flock size class. Weighted percentages of sheep protected or affected by producers' use of each method were computed similarly. Similar estimates also were prepared for eastern and western regions of the U.S. and for the U.S. as a whole. Eastern and western regions were defined as APHIS Wildlife Services Eastern and Western regions. The eastern region includes Minnesota, Iowa, Missouri, Arkansas, Louisiana, and all states east of these; the western region consists of North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Texas and all more westerly states.

The original report on this survey (NASS 1995a) noted that the results were subject to sampling variability but did not provide statistical estimates of variability. The authors quantified sampling variability by computing 95% confidence intervals (CIs) for each percentage estimate. Each CI was calculated as the estimate plus or minus a "t" value times a standard error (SE). Student's "t" values for $p = 0.95$ were obtained from a standard "t" table (Simpson et al. 1960:422). SEs for unweighted data were computed using the normal approximation for binomial distributions (Simpson et al. 1960). SEs for weighted estimates were provided by the SUDAAN software.

CIs were used to distinguish genuine differences from chance sampling variations. In general, it was considered any apparent difference between any two percentage estimates to be statistically significant when neither estimate was included within the CI of the other.

This analysis yielded a series of large tables that were too voluminous for presentation in this paper. The findings are summarized here, and are described in greater detail in Connolly and Wagner (1998).

RESULTS

This survey provided information about sheep producers' use of 6 NL predation control methods or method groups in 1994. Based on the authors' weighted estimates, 34% of the nation's sheep producers used fencing during 1994. Twenty-five percent used husbandry, 20% used guard animals, 4% used frightening tactics, 0.3% used aversion, and 3% used other methods. An estimated 45% of U.S. sheep producers used no NL predator control methods (Table 1).

Guard animals and frightening tactics were used by higher percentages of sheep producers in western states than in eastern states. Other methods were used by generally similar percentages of western and eastern producers, although large operations (size class 4) in the west used aversion at a higher rate than those in the east (Connolly and Wagner 1998).

A general pattern of association was seen between flock size and use of each NL method or method group (Table 1). The percentages of operators using each method were lowest for small flocks (size class 1), higher for intermediate size classes 2 and 3, and highest for large operations (class 4). Conversely, the percentage of producers who reported using no NL methods was largest for small flocks and smallest for large operators.

Weighted estimates for numbers of sheep revealed that 33% of all U.S. sheep were protected by fencing in 1994. Forty percent were protected by husbandry, 39% by guard animals, 12% by frightening tactics, 2.4% by aversion, and 5% by other methods. Overall, 70% of the nation's sheep were protected, and 30% were not protected by one or more NL predator control methods in 1994 (Table 2).

Except for fencing, the percentages of sheep protected by each NL method were greater in western states than in eastern states. Conversely, the percentage of sheep not protected by any NL method was 38% in eastern states, but only 28% in western states.

Estimated percentages of sheep that were protected by NL control methods tended to increase with flock size (Table 2). Except for fencing, the percentages of sheep protected by each method were lowest on small farms (flock size 1), higher in flocks of intermediate size, and highest on large operations (flock size 4). Fencing, in contrast, protected 37% of the sheep on both small and large operations, and smaller fractions of the sheep in operations of intermediate size.

For all NL methods except fencing, the percentage of sheep protected by each method (Table 2) was greater than the percentage of producers who used that method (Table 1). Consistent with this observation, only 30% of the nation's sheep were not protected by NL methods even though 45% of U.S. sheep producers used no NL method.

Unweighted survey data also showed different rates of use for the six control methods or method groups, as well as differences among flock size classes in the percentages of respondents who reported using each method (Connolly and Wagner 1998). For most control methods and flock size categories, the percentage of respondents who reported using the method was intermediate between the corresponding, weighted estimates for percentages of sheep producers (Table 1) and percentages of sheep protected (Table 2). These results are consistent with the sampling design that intentionally oversampled large operations (NASS 1995a).

DISCUSSION

The information presented in this paper is based on information from 8,451 sheep producers—10.3% of the nation's 82,120 sheep operations at the time of the survey (Table 1, footnote 1). This sample size is regarded as more than adequate to yield accurate information on predation management practices of the U.S. sheep industry. It should be noted, however, that the 1995 NASS survey did not question producers about all predation controls. It concentrated on NL control measures even though most sheep producers use both lethal and NL methods.

This analysis confirms the conclusions of NASS (1995a) regarding the relative frequency of use for various NL predation control measures. Fencing, guard animals, and husbandry were used most, frightening tactics and other methods less, and aversion was used very little.

Table 1. Use of non-lethal predation control methods by U.S. sheep producers in 1994.

Flock[1] Size	Non-lethal Methods and Methods Groups						
	Fencing	Husbandry	Guard Animals	Fright Tactics	Aversion	Others	No NL Method
	Percent of Producers Who Used Each Method[2]						
1	35 27-43	24 17-30	17 12-23	3 1-4	0.2 0.0-0.3	2 1-3	47 37-56
2	28 24-33	29 25-34	26 23-30	6 4-7	0.5 0.1-0.9	4 3-5	40 35-45
3	25 20-31	30 24-35	36 30-41	7 6-8	1.0 0.5-1.5	6 5-8	38 34-43
4	30 28-32	43 40-45	42 39-44	15 13-17	2.4 1.8-2.9	7 6-8	28 26-31
ALL	34 28-40	25 19-30	20 16-24	4 3-5	0.3 0.2-0.4	3 2-3	45 38-53

[1]Size class 1 = 1 to 49 sheep; 2 = 50 to 199 sheep; 3 = 200 to 999 sheep; and 4 = 1000+ sheep. On January 1, 1995, the United States had approximately 82,120 sheep operations (NASS 1996b). Their distribution by flock size was class 1—79.2%; class 2—14.3%; class 3—5.0%; and class 4—1.6%
[2]Hyphenated numbers are 95% confidence intervals.

Table 2. Percentages of sheep in the U.S. protected by non-lethal predation control methods in 1994.

Flock[1] Size	Non-lethal Methods and Methods Groups						
	Fencing	Husbandry	Guard Animals	Fright Tactics	Aversion	Others	No NL Method
	Percent of Sheep Protected by Each Method[2]						
1	37 30-43	27 20-33	20 14-26	3 2-4	0.2 0.1-0.3	2 1-4	41 35-47
2	28 24-31	30 26-34	28 24-32	6 5-8	0.5 0.2-0.9	4 3-5	39 35-43
3	26 19-32	31 25-37	37 32-43	7 6-9	0.9 0.5-1.3	6 5-8	37 32-41
4	37 34-39	49 46-52	48 45-51	18 16-20	4.0 2.8-5.2	6 5-7	22 20-25
ALL	33 31-35	40 38-42	39 37-42	12 11-13	2.4 1.8-3.0	5 5-6	30 28-32

[1]Size class 1 = 1 to 49 sheep; 2 = 50 to 199 sheep; 3 = 200 to 999 sheep; and 4 = 1000+ sheep. On January 1, 1995, the United States had approximately 8.886 million sheep and lambs (NASS 1996b). Their distribution by flock size was class 1—12.0%; class 2—13.9%; class 3—21.9%; and class 4—52.2%
[2]Hyphenated numbers are 95% confidence intervals.

This analysis went beyond that of NASS (1995a) in estimating the percentages of sheep producers who used each method and the percentages of sheep protected by each method. These estimates showed that most U.S. sheep producers used one or more NL predation management practices in 1994, and that about 70% of sheep in the U.S. were protected by one or more NL predation control measures. Both measures of NL method use were higher in western states than in eastern states.

The results of the analysis by flock size classes confirmed the hypothesis that NL predation controls were used more in large sheep operations than in small ones. In addition, weighted estimates reveal that the percentages of sheep protected or affected by the use of NL control measures were much higher than could have been inferred from the original report (NASS 1995a).

Comparing the authors' weighted estimates to the unweighted survey data, it was concluded that the unweighted statistics did not represent either sheep producers or sheep numbers as well as the weighted estimates. This finding seems logical, considering that the original analysis was not designed to estimate either the percentages of U.S. sheep producers who used various predation controls or the percentages of the nation's sheep industry that were protected by such methods.

It follows that reanalysis, including weighting as appropriate, is warranted whenever users of survey data want information that was not extracted in the original analysis. In this case, weighted analyses yielded useful information that was not presented in the original summary (NASS 1995a). NASS is commended for devising a recording system that preserved the original data in a form that was conducive to reanalysis.

An important finding in this survey is that many U.S. sheep producers reported using no NL predation control measures in 1994. As noted previously, the highest percentage rates of method non-use were on small operations (size class 1) and the lowest rates were on large operations (class 4; Table 1).

Why did not all sheep producers use NL predation controls? Part of the answer to this question, the authors believe, is that the risk of predation differs among sheep ranches. Balser (1974), for example, showed that approximately half of 111 ranchers interviewed in Utah and New Mexico had losses below 5% annually, while one-fourth reported over 10% predator losses. It is speculated that sheep producers' predation management efforts in 1994 varied with their perceived risk of predation. Those lucky producers who expected to have little or no predation probably did not devote major effort to predation control.

This study indicated that aversion was used by few sheep producers in 1994. "Aversion," as defined in the NASS questionnaire, included both repellents and aversive conditioning. No known repellents or aversive conditioning products that are effective and practical for protecting livestock from predators. None were registered or legally available in 1994, so it was not expected to have even small numbers of respondents to report the use of such materials.

As noted above, approximately 3% of U.S. sheep producers reported using "other" NL predation control measures. The "other" measures were not further identified in NASS (1995a) or in unpublished data available to the authors. They may have included shed lambing, harassment, scarecrows, and other practices that were not specified in "husbandry" or other method categories as defined in the survey instrument.

It should be recognized that the 1995 survey dealt rather superficially with sheep producers' predation management practices. Survey data based solely on producers' statements that they used or did not use specific methods give no weight to the quality or intensity of method use. A thorough analysis of predator management practices would entail better documentation of producers' level of effort with each method, coupled with assessments of effectiveness in reducing losses. The 1995 survey was a good start toward improved documentation of livestock producers' NL predation management practices, but much more remains to be done.

Another study of sheep producers' predation management practices was carried out in January 1996 as part of an animal health survey by APHIS's National Animal Health Monitoring System (NAHMS 1996a,b). This mail survey improved upon the 1995 NASS survey in two important respects—it included both lethal and NL predation control methods, and producers were asked for subject evaluations of method effectiveness. Approximately 66% of the operators used at least one lethal or NL predator management practice.

NAHMS' study found that 41% of U.S. sheep operations used one or more lethal methods, and 34% used guard animals. Among species of guard animals, llamas and dogs were rated as more effective than donkeys. However, the highest effectiveness rating went to "other" methods including night penning, other lights and noises, and "USDA:APHIS Animal Damage Control".

More recent NASS surveys also have recorded producers' assessments of predator control method effectiveness in selected states. Sheep producers in Colorado (CASS 1998) and Montana (MASS 1998) were asked to rate each of the NL control measures they used in 1997 as "very effective," "somewhat effective," or "not effective." The most effective methods in both states included herding, night penning, and shed lambing. Guard animals and fencing received higher effectiveness ratings in Montana than in Colorado. Similar data may have been collected in other states in 1998.

Perhaps the most detailed survey to date of livestock producers' NL predator management practices was carried out by APHIS Wildlife Services (WS) personnel in New Mexico in 1994. Livestock producers and other WS program cooperators were surveyed to determine what NL methods had been tried, how much it cost to implement the methods, which methods were successful, why some methods were discontinued, and whether lethal methods also were used to reduce agricultural and other property losses. The results were summarized by May (1996).

Livestock producers in New Mexico reported total expenditures of approximately $43.5 million on NL predation controls; most of these expenditures were for net wire fencing. Most of the NL methods implemented by livestock producers were still in use at the time of the survey, even though many producers had discontinued using specific methods because they were ineffective or too costly. When New Mexico livestock producers were asked if specific NL methods they used reduced losses to an acceptable level, 80% of the responses were "no." Ninety percent of survey respondents used both lethal and NL methods.

Considering this study in conjunction with others cited in this paper, two basic conclusions seem to be warranted. First, most U.S. sheep producers use NL as well as lethal predation management methods. Second, livestock producers tend to select and use the control methods that they believe will be most practical and effective in their operations.

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AMENDMENT 14—COLORADO'S ANTI-TRAPPING INITIATIVE, A HISTORY AND PERSPECTIVE ON IMPACTS

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ABSTRACT: In November 1996, Colorado voters approved constitutional Amendment 14, an anti-trapping initiative, which prohibited the taking of wildlife with any leghold trap, any instant kill body-gripping design trap, or by poison or snare. Several exemptions were provided. This paper summarizes the history of events leading up to the introduction of the Amendment, and examines some of the initial impacts on the federal Wildlife Services program, the sheep industry, and the people of Colorado.

KEY WORDS: trapping initiatives, trap bans, initiatives, leghold traps

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INTRODUCTION

In March 1994, the Colorado Division of Wildlife (CDOW) revised its Long Range Plan outlining broad direction and priorities for the Division over the next 15 years. Goal number 11 of the plan directed the agency to "develop and apply standards for trapping practices that are consistent with public expectations for humane treatment of animals" (Colorado Division of Wildlife March 1994). In August 1994, a multi-disciplinary team of policy analysts from the CDOW was assembled to review the Division's furbearer management policy and regulatory issues. One of the team's objectives was to increase the level of information to all players in the process so that the Division fully understood the perspectives and positions of stakeholders and citizens and vice versa. To help obtain human dimensions information related to trapping, the team requested Colorado State University's Human Dimensions in Natural Resources Unit (HDNRU) to conduct a telephone survey on public attitudes towards trapping. Sixty-one percent of those surveyed would ban trapping if given an opportunity; twenty-nine percent would allow trapping to continue; and ten percent didn't know. Fifty-three percent supported the use of traps to prevent damage to livestock or property.

In November 1994, the CDOW contracted with a private firm, CDR Associates of Boulder, Colorado, to facilitate a Furbearer Management Review Stakeholder's process. The Stakeholder Committee's charge was to develop recommendations on furbearer management for the Colorado Wildlife Commission to consider. Committee members included individuals from the Colorado Department of Agriculture, U.S. Department of Agriculture, CDOW, Colorado Trapper's Association, Colorado Cattlemen's Association, Colorado Woolgrower's Association, United Sportsmen's Council, Colorado Wildlife Federation, and various environmental and animal welfare/rights groups.

At about this same time voters in Arizona passed Proposition 201 amending state statutes making it unlawful to take wildlife with any leghold trap, any instant kill body-gripping design trap, or by a poison or snare on any public land. This provided additional impetus to the effort being undertaken by the CDOW.

The Stakeholder's Committee was unable to reach consensus on a number of issues after five months of meetings; nevertheless, they developed four alternatives and presented them to the Wildlife Commission. The most restrictive of the alternatives allowed trapping only to protect human health and safety; the least restrictive alternative required few changes to regulations in place at the time. The Wildlife Commission directed the DOW staff to develop a preferred alternative to be presented to the Commission at their workshop scheduled for June. This was done, and final regulations were adopted by the Commission at their July meeting.

Some of the notable changes to existing regulations were: 1) the use of padded-jaw traps was mandated by March 1, 1997; 2) killing snares were made illegal, and new regulations required the use of restraining snares which had to be checked every other day; 3) aerial hunting permits were shortened from 90 to 30 days; 4) no preventive control was allowed; 5) the number of species that could be trapped was reduced from 18 to 8 (the 8 were species previously determined to be those most commonly involved in depredation or nuisance problems); and 6) a season was set for coyotes (November 30 to February 28; the season had been year-long).

Following adoption of the CDOW regulations, the Department of Agriculture attempted to develop a Memorandum Of Understanding (MOU) with the CDOW to deal with some of their ongoing concerns. The CDOW backed away from this process in December saying that any further negotiations would have to include Furbearer Stakeholder Committee members.

On January 3, 1996 a group calling itself CPAWW (Colorado People Allied With Wildlife) presented language for Amendment 14 to the Secretary of State's office. Several individuals who had participated in the CDOW furbearer management review stakeholder process took the lead in getting the Amendment introduced. Amendment 14 language was very similar to that contained in Arizona's Proposition 201, with the exception that the prohibitions on traps, snares, and poisons covered private as well as public land.

Following this action, in January 1996, agriculture decided to go to the legislature to clarify the authority of the Commissioner of Agriculture in predator control. The reason for the confusion was that there was an existing agriculture statute, Title 35-40-101, which gave the Commissioner of Agriculture authority to promulgate rules for the taking of predators. No rules had ever been promulgated under this authority.

Senate Bill 96-167 was introduced to the Colorado legislature in January 1996. SB 96-167 amended several sections of Title 33 and 35 of the Colorado Revised Statutes. The word predator was changed to depredating animal, a list of animals was established that the Agriculture Commissioner had authority to control, designees were allowed to assist landowners with damage problems, and several definitions were established. Contrary to some public opinion, SB 96-167 did not transfer authority to the Department of Agriculture to manage predators, it merely clarified existing authority. Senate Bill 96-167 was passed by the legislature in March and signed by the Governor in April of 1996.

Signatures to qualify Amendment 14 for the November ballot were gathered between January and July 1996. CPAWW obtained 54,000 (5% of the vote for the Secretary of State in the last election) valid signatures to qualify the initiative for the ballot. The opposition had two and a half months to mount a campaign against the initiative. The Colorado Woolgrowers headed the opposition spending nearly $42,000 on their campaign. Amendment 14 backers spent nearly $200,000.

In the meantime, the Department of Agriculture proceeded to develop regulations for taking certain depredating animals under authority clarified in SB 167. These regulations were developed by a roundtable committee and finalized on November 1, 1996. Many members of this committee had served on the CDOW Furbearer Management Review Committee.

Some notable changes were made to existing CDOW regulations. The CDOA regulations allowed: 1) the use of killing snares which could be checked once a week; 2) traps to be checked three times a week (this was critical to the Wildlife Services (WS) program considering that traps could now be left functional over weekends); 3) designees to assist landowners suffering damage from depredating animals; 4) extending aerial hunting authorizations to 90 days; 5) a trade-in program for unpadded traps; and 6) WS personnel to take depredating bear and lion without prior approval from the CDOW.

On November 5, 1996 the voters of Colorado passed Amendment 14 by a 52% to 48% vote. The Amendment passed in only 16 of 63 counties with 51% of the "yes" vote coming from four, mostly urban, counties: Denver, Jefferson, Boulder, and Arapahoe. On January 15, 1997 the Governor proclaimed Amendment 14 law.

Legislation to interpret and implement certain provisions of the Amendment was included in Senate Bill 97-52 which was introduced in January and passed in May 1997.

As instituted, Amendment 14 prohibited the taking of wildlife with leghold traps, instant kill body-gripping traps (conibears, etc.), snares (leg and neck), and poisons (M-44s and denning cartridges) with the following exemptions: 1) for bird and rodent control other than beaver and muskrat; 2) for the taking of fish or other nonmammalian aquatic wildlife by the CDOW; 3) for the taking of wildlife for the purpose of protecting human health or safety by federal, state, county, or municipal departments of health; 4) for the use of nonlethal snares, traps not specifically designed to kill, or nets to take wildlife for the purposes of: (a) bona fide scientific research, (b) falconry, (c) relocation permitted in accordance with rules of the CDOW, or (d) medical treatment of the animal being captured; 5) for landowners and lessees of a parcel of private property used primarily for commercial agriculture, or their employees, to use these devices if other legal lethal or non-lethal methods failed to alleviate a particular problem. Before being allowed to use the prohibited methods, a property owner or lessee would have to present on-site evidence to the CDOW that ongoing damage to livestock or crops had not been alleviated by the use of methods other than those prohibited by the Amendment. Authorizations to use prohibited methods would not exceed one 30-day period per calendar year per parcel.

The Colorado WS program ceased using all leghold traps, conibear traps, neck snares, mechanically powered leg snares, large denning cartridges, and M-44s on January 23, 1997, but resumed using these devices in May 1997 following the signing of Senate Bill 52. All current use of these devices occurs on private property and during 30-day exempted periods.

This paper examines some of the impacts of Amendment 14 on the WS program, the sheep industry, and the people of Colorado.

METHODS

Data from the Colorado Wildlife Service program's Management Information System (MIS) were used to analyze impacts of Amendment 14 on program take of coyotes, black bear, and mountain lion with leghold traps, neck snares, mechanically powered leg snares, M-44s, and large denning cartridges. MIS information on confirmed (verified by Wildlife Services personnel) losses of sheep and lambs to coyotes, black bear and mountain lion was also analyzed. The MIS system has been functional in Colorado since April 1994 and records a variety of information on program activities such as number of properties worked, time spent on these properties, status of these lands (e.g., federal, state, private), confirmed damage, control tools placed and removed, numbers and species of animals taken, and control recommendations given.

These data were organized by Agricultural Statistics Service district. There are six such districts established in the State of Colorado: 1) Northwest and Mountain; 2) Northeast; 3) East Central; 4) Southwest; 5) San Luis Valley; and 6) Southeast. The program is currently not operational in the Northeast or East Central Districts. The program in the Southeast District has not been in place long enough to be considered in this analysis. Personnel changes as well as changes in program emphasis in the San Luis Valley District also make it unavailable for analysis. Therefore, only information from the Northwest and Mountain and the Southwest districts (Figure 1) was analyzed. The years analyzed were federal fiscal years (October 1 through September 30) 1995, 1996 and 1997.

COLORADO AGRICULTURAL STATISTICS DISTRICTS

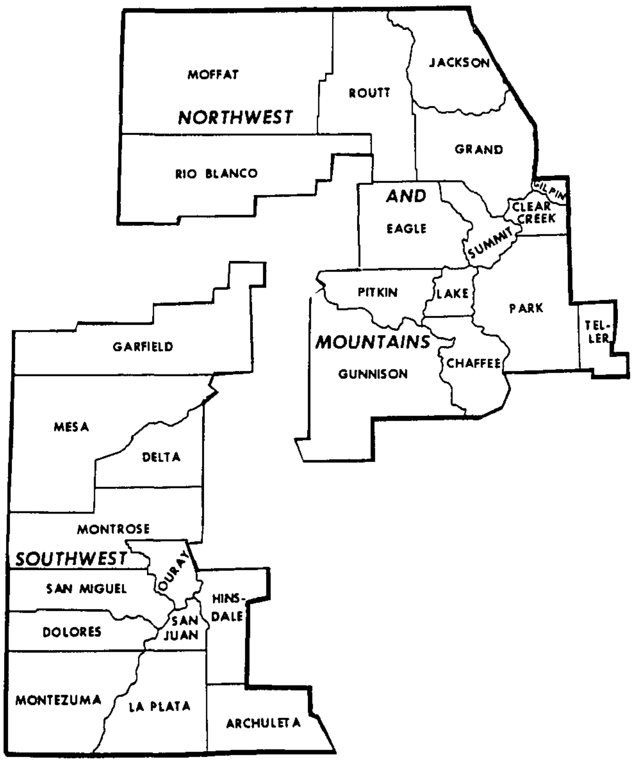

Figure 1. Colorado Agricultural Statistics Service Agricultural Districts, Northwest and Mountain and Southwest.

RESULTS

Impacts on the Use of Control Methods/Tools

Leghold Traps. Leghold traps have historically been used in the Colorado WS program primarily to capture coyotes. Leghold traps have been used on public and private land in both agricultural districts. Even though the WS program assisted landowners during an unknown number of 30-day exempted periods during fiscal year (FY) 1997, leghold trap take of coyotes decreased dramatically between FY 1996 and FY 1997 in both districts (Figure 2).

Neck Snares. Neck snares have historically been used by the WS program to take both coyotes and beaver. These devices have been used on public and private land in both agriculture districts. Figure 3 illustrates the decrease in coyote take with these devices in both districts during FY 1997. Although take had declined between FY 1995 and 1996, the decline was more dramatic between FY 1996 and FY 1997.

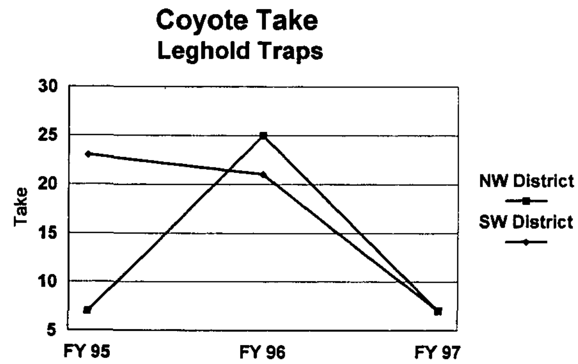

Figure 2. Leghold trap take of coyotes, Northwest and Southwest Agricultural Districts, Fiscal Years 1995 to 1997.

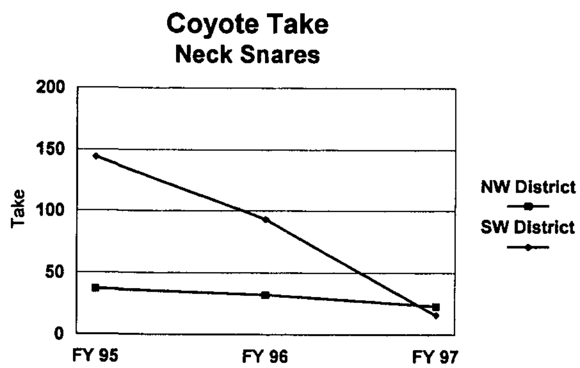

Figure 3. Neck snare take of coyotes, Northwest and Southwest Agricultural Districts, Fiscal Years 1995 to 1997.

M-44s. M-44s are registered in Colorado for the taking of coyotes, red fox, gray fox, and feral dogs that are depredating on livestock or federally listed threatened and endangered species. They are registered for use only by APHIS Wildlife Services personnel. Historically, they have been used only on private land. Even though coyote take with M-44s had declined between FY 1995 and FY 1996 in both districts, take in FY 1997 was dramatically lower (Figure 4).

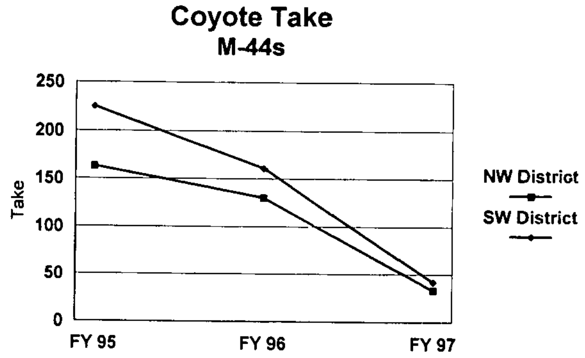

Figure 4. M-44 take of coyotes, Northwest and Southwest Agricultural Districts, Fiscal Years 1995 to 1997.

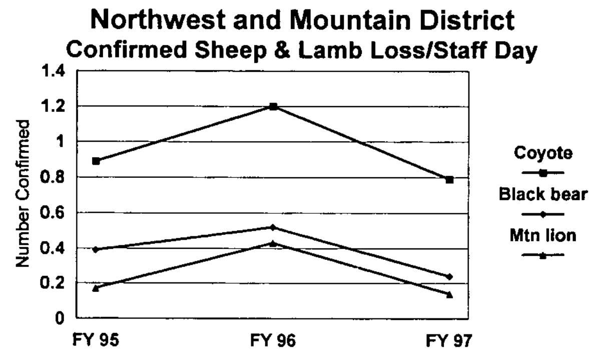

Figure 5. Confirmed sheep and lamb loss/staff day, Northwest and Mountain Agricultural District, Fiscal Years 1995 to 1997.

Mechanically Powered Leg Snares. Mechanically powered legsnares have historically been used by WS personnel to capture both black bear and mountain lion. These devices have been used on public and private land in both agricultural districts. During the two years preceding the passage of Amendment 14, program personnel in the Northwest District used legsnares to capture 15 and 11 black bear, respectively. They also took one mountain lion in FY 1996. In FY 1997, one black bear and one mountain lion were taken with legsnares. In the Southwest District personnel used legsnares to take 11 black bear in FY 1995, and three black bear in FY 1996. They also took three lion in FY 1995, and two in FY 1996. In FY 1997, one black bear and no mountain lion were taken with legsnares.

Large Denning Cartridges. Even though the WS program did not use these devices much prior to the passage of Amendment 14, many cooperators in the Northern and Mountain District used them extensively to control depredating red fox.

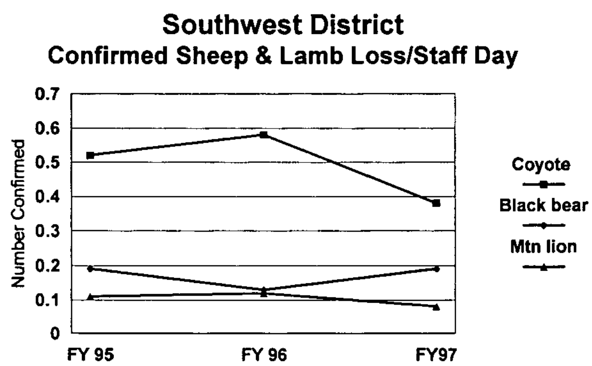

Figure 6. Confirmed sheep and lamb loss/staff day, Southwest Agricultural District, Fiscal Years 1995 to 1997.

IMPACTS ON LIVESTOCK DAMAGE, SPECIFICALLY SHEEP

Wildlife Services Confirmed Loss

Northwest and Mountain District. The Northwest and Mountain District encompasses a 14 county area (Figure 1) that has historically been the major sheep raising area of the state. Program personnel spent 553 staff days in FY 1995, 731 staff days in FY 1996, and 785 staff days in FY 1997 protecting sheep on rural properties within this district. Figure 5 shows the trend in WS confirmed sheep and lamb loss to coyotes, black bear and mountain lion during fiscal years 1995 to 1997.

Southwest District. The Southwest District is a 12 county area (Figure 1) of the state that has supported a WS program for a number of years. WS personnel spent 685 staff days in FY 1995, 608 staff days in FY 1996, and 455 staff days in FY 1997 protecting sheep on rural properties. Figure 6 shows the trend in confirmed sheep and lamb loss to coyotes, black bear and mountain lion during FYs 1995 to 1997.

DISCUSSION

Impacts on Control Methods

Leghold Traps. The Colorado WS program did not use leghold traps extensively prior to the passage of Amendment 14. Historically, personnel in the Southwest District depended more on these devices than personnel in the Northwest District. The reason for this seems to be related to workloads. The requirement that traps be checked every 48 hours hindered use in areas where workloads were heavy, like the Northwest District. When leghold traps were used, they were used to capture coyotes that had eluded other methods or because they were considered the ideal method for a particular problem.

Leghold traps are now used only during authorized 30-day periods on private land and are checked three times a week. As a result of Amendment 14, the Colorado program has lost some of its ability to selectively remove individual predators.

Neck Snares. Prior to Amendment 14, neck snares were one of the more important control tools for taking depredating coyote and nuisance beaver. These devices are now illegal to use on public land and can only be used during a 30-day exempted period on private land. One advantage of neck snares for coyotes is that they are not labor intensive. They can be set in a short period of time and checked once a week. In the hands of a skilled professional they are selective for the targeted animal. The Colorado WS program has lost some of its ability to selectively remove individual offending animals due to the restrictions imposed by Amendment 14.

M-44s. M-44s were the most important method used to deal with depredating coyotes in the Southwest District prior to the implementation of Amendment 14. In the Northwest they were the second most important tool. These devices had only been used on private land in Colorado and only by WS personnel. One important advantage of M-44s is the low cost to use them. Secondly, they are selective for the target species. Much of these advantages have been lost due to Amendment 14.

Mechanically Powered Leg Snares. Mechanically powered leg snares were the most important control tool used by the WS program to capture black bear and mountain lion prior to the passage of Amendment 14. These devices are now illegal on public land and can only be used during authorized 30-day periods on private land. The only effective methods now available to WS personnel, to deal with black bear and mountain lion on public lands, are trailing dogs and live traps.

Not all specialists have trailing dogs, and the use of trailing dogs is time consuming and, therefore, more costly than using leg snares. Dog packs must also be maintained yearlong. An average pack costs the WS program $1,200/year and there are additional costs borne by individual houndsmen. In some areas the use of trailing dogs is not practical, such as areas where the dogs might be killed running across highways or through private property. Some WS specialists feel that trailing dogs are becoming less effective for bear in Colorado due to continual presence of guard dogs. Bears seem to be fighting the dogs more rather than treeing. This makes it more difficult for the houndsman to get to the animal to dispatch it. With the implementation of the new CDOA regulations, and prior to Amendment 14, it would have been possible for WS specialists to set legsnares near confirmed bear or lion kills immediately, thus increasing the likelihood of capturing the offending individual. With the delay associated with bringing in dogs from a remote location, or getting an authorization to set a snare on private property, selectivity decreases.

Live traps have not been used by the Colorado WS program historically, but several are on order and will be tried. Live traps are difficult to get into areas not accessible by vehicle.

Denning Cartridges. Denning cartridges were used infrequently by WS personnel, but their complete prohibition on public land may make it difficult to humanely dispatch coyote pups if the adults are taken by other means.

Impacts on Livestock Damage, Specifically Sheep

WS Confirmed Damage. Sheep damage as confirmed by WS personnel per staff day for black bear, coyote, and mountain lion declined slightly during FY 1997 in both agricultural districts. The only exception was bear damage in the Southwest District. Several factors may have contributed to this decrease. First, as far as black bear and mountain lion damage is concerned, the CDOW reduced some cooperative funding ($36,600) at the end of FY 1996. This money had been used in FYs 1995 and 1996 to offset WS costs associated with investigating bear and lion complaints for the CDOW. Without this compensation, the WS program was not able to investigate as many bear and lion complaints during FY 1997 as in previous years. Also, the spring of 1997 was a very wet one, and this could have contributed to more feed for bears which may have impacted predation on sheep. The wet weather could have also had an impact on rodent populations and thus coyote damage to sheep. Delays associated with getting authorizations to use equipment may also have contributed to the decline. The change from using control equipment, which was typically set in the area of depredation and checked frequently, to using other methods such as calling and shooting, decoy dogs and aerial hunting may also have had an impact.

Colorado Sheep Industry Perspective

Colorado currently has about 1,100 sheep operations in the state. January 1, 1998 sheep inventory was 575,000 head that has a estimated value of over $60 million. Colorado is the fourth largest state in total sheep and lambs, second in lamb feeding and seventh in production of breeding sheep. The sheep industry is important to the economy of Colorado and predator losses are a major economic factor for sheep producers.

The sheep industry in Colorado has been monitoring the losses to predators over the last four years. The trends for losses to bears and lions has been steady during that time frame with a slight increase in losses to bears. However, the losses to coyotes had been decreasing until 1997. Sheep losses to coyotes were 18,900 head in 1994, 16,100 head in 1995, 15,000 head in 1996, and up to 21,700 head in 1997, a 45% increase in one year.

It is the opinion of Colorado sheep industry leaders that there is only one reason for this spike in losses—the effects of Amendment 14. This amendment has extremely limited the use of the most effective tools available to take individual animals causing depredation damage. By not having year-round access to traps, snares and M-44s, sheep producers have suffered significant losses, which will probably increase during the coming years.

During this same time period, many of the producers have either begun using non-lethal techniques, such as guarding animals, scare devices, fencing or penning at night or increased the use of non-lethal methods. In 1994, 36% of sheep producers were reported as using some type of non-lethal predator control. In 1997, that number increased to 80%, yet losses were still escalating.

Sheep producers in Colorado now have little practical defense against predators. Calling and shooting is effective in some situations but most sheep people are not marksmen and do not have the skills or the time available to manage predators with this method.

The current law does allow producers to use traps or snares for one consecutive 30-day period for each individually recorded parcel of property. WS personnel can assist with those tools during that period and use M-44s as well. Many producers with large acreages are able to provide protection on almost a year round basis as they have several different parcels of property involved.

However, even with the exception, there is still a limited number of WS personnel available during the critical times of the year to prevent losses to depredating animals.

It is obvious to many people in Colorado that managing wildlife by public initiative is not only having a significant impact on the livestock industry but many other areas, including wildlife and pets. The Colorado Woolgrowers' Association will continue to monitor the losses to predators over the next several years and evaluate the effects of Amendment 14 on the livestock industry and wildlife.

In the meantime, producers are having to struggle with a small variety of legal methods to protect their sheep and cattle from predators. Hopefully, these people will not be forced into criminal activity in an attempt to protect their livelihood.

Human Health and Safety

Amendment 14 gave federal, state, county and municipal departments of health the authority to authorize the use of prohibited methods to take animals considered to be threats to human health and safety. Most health departments can recognize and deal with threats to human health from wildlife, but few have expertise in protecting human safety from wildlife. Although language in the amendment gave health departments the authority to authorize the use of prohibited methods, it gave them no statutory authority to set regulations. Attempts are now being made at the state level to draft guidelines for all county and municipal health departments to use in human health and safety situations. Because these are only unenforceable guidelines, there could be inconsistent statewide application which will ultimately cause confusion and frustration for the public.

Beaver Control

Due to the passage of Amendment 14 individuals suffering from beaver damage to property, not considered agricultural, are limited to shooting and live trapping. Shooting in many urban settings is not safe or practical and live trapping can be very expensive if a property owner has to purchase the traps.

Protection of Pets

One problem that has surfaced since the passage of Amendment 14 is coyotes killing urban pets, mostly cats and small dogs. In the past, private pest control operators handled many of these complaints using leghold traps. The only effective way now to deal with this type of problem is to shoot the offending animal. Live traps are not considered effective for catching adult coyotes. In many situations firearms are not allowed, due to local restrictions, or safety considerations. It appears that health departments are not going to authorize the use of prohibited methods to take coyotes that are killing pets. It is believed that this problem will continue to escalate as people move into rural areas and as more coyotes become established in urban areas.

Threatened/Endangered Species

There are no exemptions provided in Amendment 14 for use of prohibited methods to take predators to protect threatened or endangered species. Colorado is planning to reintroduce black-footed ferrets into the northwest part of the state. If coyotes prey on these ferrets, only aerial hunting and ground shooting would be legal to protect them. Aerial hunting would probably not be practical during certain times of the year such as big game hunting seasons. If wolves were ever reintroduced into Colorado, Amendment 14 might cause some problems for management of this species as well.

Cooperative Dollars Provided to the Wildlife Services Program

Cooperative support, in the way of dollars provided to the WS program, in the Northwest and Southwest Districts has remained relatively stable during the first year following implementation of Amendment 14. Support in other parts of the state, mostly the eastern plains, has actually increased since the passage of the Amendment. It is believed that this can be attributed to several factors. One is that cattle growers are expressing increased interest in cooperating with the WS program perhaps because of increased predation on calves. Many cattle and sheep growers also consider aerial hunting to be the only effective method left to deal with coyote problems, and WS is the only entity offering this service at this time.

CONCLUSION

Some of the short-term impacts of Amendment 14 on the federal WS program, the livestock industry, and the people of Colorado have been pointed out. Longer term impacts on the livestock industry will not be known for a number of years. It is the intent of the authors to revisit this forum in two years to report on whether WS has been able to continue providing an effective program for protecting livestock and other important resources in Colorado.

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MANAGING ISLAND BIOTAS: BROWN TREESNAKE CONTROL USING BARRIER TECHNOLOGY

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ABSTRACT: The brown treesnake (*Boiga irregularis*), accidently introduced to the previously snake-free U.S. island of Guam after World War II, decimated the island's naive wildlife. Today, it periodically stows away on craft going to other islands where the ecological damage may be repeated. Barriers offer an effective tool for keeping the snakes out of areas from which they can disperse off-island, as well as sites identified as critical for the protection of human health, conduct of economic activity, or conservation of endangered species. The authors have developed a variety of barrier designs which repulse at least 95% of snake attempts to scale them under laboratory conditions; the best performing models are 100% effective. Three of the designs are in operational use. Designs for maximizing snake repulsion will be more costly to build, but may have lower annual costs due to reduced expenses for system upkeep.

KEY WORDS: brown treesnake, *Boiga irregularis*, barrier, vertebrate pest control, Guam

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INTRODUCTION

The brown treesnake (*Boiga irregularis*) was accidentally introduced to Guam in the late 1940s. Taking advantage of high densities of introduced and predator-naive prey species, it irrupted to very high levels, causing the extirpation or serious decline of most native vertebrates, millions of dollars in damages due to power outages, costly losses of agricultural stock, and a health risk to human infants (Rodda et al. 1998a).

The snake is an excellent climber, using minute irregularities to ascend almost any structure, is extremely efficient at entering small openings and hiding in them for protracted periods, and can survive for months without food. This allows it to be accidentally transported in both sea and air cargo. The snake's ability to store sperm (Whittier and Limpus 1996) raises the disturbing possibility that even a single dispersing female may be able to start a new population. Brown treesnakes have been found associated with Guam cargo in destinations as diverse as Diego Garcia Island in the Indian Ocean and Spain, but most reports have come from Saipan in the Mariana Islands and Oahu in the Hawaiian Islands (Fritts et al. 1998).

Two main management goals suggest themselves: 1) further spread of the snake should be prevented; and 2) Guam's snake population should be controlled, both to reduce the risk of further spread and to begin restoring affected ecosystems. Until the tools are developed for snake eradication, blocking snakes from entering sensitive areas such as electrical power systems, airports, and conservation areas is likely to be the best strategy (U.S. National Research Council 1996; Rodda et al. 1998b).

Some operational uses will require a temporary barrier (e.g., one-time military exercises); other uses are recurring or continuous (protection of endangered species from snake predation). Over the past seven years, several types of barriers have been developed to prevent movement of brown treesnakes into or away from designated areas (Campbell, 1996; Perry et al. 1996a,b, and 1997). In this paper each of the types of barriers has been described and the advantages and disadvantages have been developed and evaluated for various situations.

METHODS

General Design Features

Besides maximal snake repulsion, each of the barriers discussed below is designed with two important features in mind. First, applications are needed both as an exclosure (preventing entrance of snakes into a protected area) and as an enclosure (preventing snake dispersal away from the enclosed area). Second, exclosures on Guam should be "self-bailing" whenever possible, so that snakes that reach the protected side by any means are able to leave easily or be neutralized with minimal effort. For example, a barrier on Guam should not keep within the exclosure a snake that accidentally enters or is brought into a cargo containment yard. Rather, the barrier should enable the snake to climb back out, or facilitate the snake's capture as it attempts to leave, so that the snake is not kept with the cargo or transported to other islands. On other islands, however, snakes that find themselves on the "wrong" side of the barrier should be trapped and killed rather than be allowed to leave as they would under the "self-bailing" principle.

Four major repulsion features are incorporated into the barriers. Three (smoothness, height, and overhang) are passive and universal. Because wind loading is a major concern in the Pacific, short barriers are more desirable than tall ones. Forcing the snakes to lean back to circumvent the overhang creates a barrier that is functionally taller, without greatly increasing wind-loading. The third feature, electrification, is active and limited to use on some types of barrier.

General Procedures

Wild-caught snakes were used, spanning the entire size range from hatchling to extremely large individuals that are uncommon in the wild. Larger snakes require taller barriers to stop them than do small snakes. Inclusion of very large snakes in the test pool allowed the authors to make more general statements about the effectiveness of barriers. The use of uncommonly large snakes provides a very conservative test of the functionality of the barrier, however, as the representation of large snakes used in tests was greater than their frequency in the wild population.

Barriers that performed well during laboratory tests advanced to field testing. Laboratory testing was of two types. Some snakes were left in a test arena overnight, and their retention was used as the metric of barrier success. When more detail was deemed necessary, an infra-red time-lapse video camera was used to record snake behavior in total darkness (i.e., no visible light), allowing precise identification of normal behaviors associated with breach attempts.

Outdoor testing was conducted under operationally realistic weather and terrain conditions. On the night they were used for outdoor tests, snakes were temporarily detained outdoors inside cloth bags, which allowed ample air circulation. At the onset of a trial, bags were untied so that snakes were free to exit the bag when they began to move. As in laboratory testing, two evaluation methods were employed. Sometimes the snakes were left in test arenas overnight and assessed their retention per night; when more detail was desired, all-night focal animal observations were conducted, during which detailed observations were made on all breach attempts.

It is not apparent what is the best measure of barrier success. For port enclosure uses, one would like to know what percentage of snakes are able to escape from the enclosure during the time when the snake is likely to be left undisturbed (generally overnight). For this application the best metric of success might be retention rate per snake-night (e.g., five snakes left in an enclosure for two nights constitute ten snake-nights, etc.). For a wildlife enclosure, however, vegetation might conceal snakes that failed to escape after their first night, providing them an opportunity to attempt escape on subsequent nights. In such a case, one might be interested in the retention rate per snake. Snakes on Guam may simply turn away and go the opposite direction if they fail to breach a snake exclosure, suggesting that for evaluating exclosure designs one might wish to know the repulsion rate per breach attempt. To accommodate these different applications, several performance measures were examined. Overall, some 1,600 individual snakes were observed making well over 11,000 breach attempts during more than 4,100 snake-nights.

Temporary Barrier

An enclosure design was tested, similar to what is being used in locations receiving suspect cargo from Guam. Full descriptions of test models were provided by Perry et al. (1996a). Briefly, the structure used in all tests was an eight-panel octagon tested outdoors. Each of the side panels was 2 m long. Number 6 rebar (nominal diameter 1.6 cm, maximum diameter 2.54 cm), inclined at 60° to create a slanting overhang, was used for all supports. Sand bags were used to secure the edge of the barrier to the ground outside the enclosure, on the snake-free side. An observation tower was placed in the middle of the enclosure and provided an elevated point from which snake behavior could be observed in all directions and recorded as it occurred without disturbing the snakes, which persistently tried to escape, repeatedly testing the barrier's efficiency. Testing began in May 1995 and continued until November 1996. Several factors were varied systematically during testing: wall materials, attachment methods, and barrier heights. Additionally, the effect of adding a pendulous flap on the top edge of the barrier was evaluated (Table 1).

RESULTS AND DISCUSSION

Snake Behavior in Test Chambers

Snake escape behavior can be divided into several stereotypical stages. Snakes typically first crawled to the nearest barrier edge, then spent some time (often over an hour) crawling along it, apparently seeking holes. The next stage also involved crawling, but included attempts to nose their way underneath the barrier. Thus, even a small gap in the seal under a long barrier is likely to afford a snake a way out. A door left open and unattended overnight will similarly create a much greater risk of escape than its size alone would suggest.

Next, snakes typically began to try and climb the barrier itself. Normally, early attempts were short, and successive attempts reached greater and greater heights. Inside corners or visual discontinuities attracted disproportionate attention, compared to uniform surfaces. Square corners are especially easy for brown treesnakes to climb, and should be avoided. Eventually, most snakes large enough to top a barrier did so, either by climbing or free-standing. This rarely took less than two hours from when the snake first emerged. In climbing, even minute irregularities in the surface of the wall were used to provide traction and allowed the snake to ascend. For example, sharp irregularities protruding only to a distance equal to the thickness of a single wire of the type found in 1/4" hardware cloth were frequently and handily used by ascending small snakes (larger snakes required larger gripping surfaces). When free-standing, a snake may raise as much as two-thirds of its body length vertically and hook its head on the top of the wall to perform a "chin-up." If the wall is vertical, a snake will prop itself against it and be able to reach greater heights than possible when it is free-standing.

Temporary Barrier

A total of 660 snakes were used in these tests. During 957 snake-nights, 3,843 attempts by snakes to scale barriers were observed. Barrier success measures are presented in Table 1.

Initial model results (test series 1-4) showed a positive relationship between snake size and the maximum height each individual achieved. However, the relationship was weak, and body length explained less than 15% of the

Table 1. Temporary barrier tests. For barrier material, "net" means netting of the kind previously used by Campbell (1996), with a hole size of 8.7 x 7.2 mm; "shade" means Solartex (Gale Group Inc., Orlando, Florida) shade cloth. Attachment method lists the technique by which the barrier was fastened to the rebar: "tie" - nylon cable binders, "sew" - cable binders and sewing, "tube" - longitudinally-slit PVC pipe. Height is minimum vertical height of the top of the barrier from the substrate (in cm). The escape path designation "furrows" indicates that the snakes were able to utilize sags in the mesh material to climb the overhanging walls.

Test Series	Material	Attach-ment	Min. Height (cm)	Flap Present	No. of Snakes Tested	% of Snakes Retained	No. of Attempts Observed	% of Attempts Repulsed	Model Escape Path(s)
1	net	tie	115	no	16	75	147	96.6	furrows
2	net	tie	115	yes	15	80	173	93.1	attach. points
3	net	sew	115	no	35	83	393	98.0	attach. points, over top
4	net	sew	115	yes	13	62	203	96.5	attach. points, over top
5	shade	tube	115	no	84	91.5	1,689	96.9	over top
6	shade	tube	130	no	76	97.4	1,238	99.6	over top

variation observed in scaling ability. This occurred because, with the exception of the smallest snakes, individuals of all size classes were sometimes able to reach considerable heights or breach the barrier altogether. Observations showed that ties and sewing allowed snakes to scale the mesh on the attachments. Also observed were some cases in which smaller snakes escaped through rips in the fabric that had gone undetected during the regular inspections. Despite this, snakes required an average of 27 attempts before finding a way to breach the barrier.

Changing mesh type and improving attachment methods significantly improved barrier performance. The preferred design (number 5) stopped well over 95% of all snake attempts to cross it and nearly 100% of snakes of normal size (the smallest snakes that were ever able to reach the top of the barrier were just under 2,000 mm in total length). This model is described in detail by Perry et al. (1996a), who also provide step-by-step instructions on how to build and best employ it.

Increasing barrier height increased retention rates (only snakes with a total length of at least 2,200 mm were consistently capable of breaching the taller barrier). However, the increase in barrier height did not statistically improve success rate per snake-night. The improvement seen in observed trials had minimal practical significance, as snakes of a size able to top the barrier in series five are very rare in nature (only about 1% of females and 5% of males in recent collections from Guam). Thus, there seems to be little reason to prefer higher (1.3 m) barriers over lower (1.15 m) ones, especially in light of the increased cost and engineering problems associated with greater wind resistance of taller fences.

Permanent Barriers

Due to space limitations, results of the large number of studies covered by this section will not be fully detailed. Instead, the three types of permanent barrier these extensive studies have led the authors to prefer will be described.

Masonry barrier. The current design is a 1.15 m high wall, with a ledge protruding out at the top for 20 cm (i.e., forming an inverted L-shape). To reach past the ledge, a snake must lean out from the vertical barrier surface, contributing to the chance of falling due to reduced contact with potential friction surfaces and the adverse angle of the approach. This shape provides passive protection that, by itself, blocked over 90% of snakes attempting to breach it (Table 2). To maximize this advantage, a 5 cm wide metal swath conducts electricity from a cattle fence charger and delivers a non-lethal high-voltage shock to any snake that reaches it. This active feature increases barrier effectiveness and, under testing conditions, raised it to 100% during nearly 1,500 nights during which a snake was pitted against the barrier.

Metal mesh barrier. This model was made of 1/4" galvanized metal mesh hardware cloth and designed to be attached to chainlink fencing. Its flat lower panel is 1.2 m high and the protruding "bulge" atop the panel has a radius of 15 cm. In this design, the bulge replaces the overhang created by the angled construction of the temporary barrier and the overhang used in the electrified barrier. Of the snakes tested indoors, 99% were prevented from breaching this barrier (Table 3). Both individuals capable of breaching it were unusually large males (total lengths of 2,320 and 2,250 mm). Furthermore, not all snakes of that size range succeeded in escaping. Retention rate of the more than 100 snakes tested in outside enclosures was statistically indistinguishable from that achieved with laboratory tests. An exclosure design allowed no free-roaming snakes in, a significantly better result than that demonstrated by an exclosure lacking snake-repulsing mesh tested over the same period in the same area.

Vinyl seawall barrier. The seawall-material barrier is constructed from vinyl sheeting (Collins Co., Camano Island, Washington) that comes in 30 cm wide sections that can be cut to a desired height with a hand saw or power tool. The material is manufactured with interlocking tabs and grooves, such that adjacent sections may be assembled into a single unit without adhesives or other anchors. Seawall barriers at heights of 1.15 and 1.52 m were tested (Table 3). The lower barrier showed 97% retention per snake-night and the higher one showed 100% success. The lower barrier was 100% successful with typical size snakes. Future testing will concentrate on larger snakes (>2 m total length) and on the feasibility and efficacy of adding an overhang or electrification.

Table 2. Retention rates for test enclosures using the masonry design. In some cases, the sample sizes include several minor variants; the variant with the highest success rate is reported in the final two columns.

Test Series	Height	Electrification	No. of Snakes Tested	No. of Snake-Nights Tested	No. of Attempts Observed	% of Snake-Nights Retained	n for % Snake Nights Retained
1	0.85	yes	43	256	2,105	20	256
2	1.00	yes	23	64	226	30	64
3	1.15	yes	232	587	3,807	100	82
4	1.15	no	115	307	--	93	307
5	1.30	yes	109	286	1,967	100	174
6	1.45	yes	86	244	--	100	244

Table 3. Retention rates for permanent barrier designs other than the masonry model. The poly mesh (high density polyethylene netting; Memphis Net and Twine, Inc., Memphis, Tennessee) had 6.5 x 6.0 mm parallelogram holes; the tensar mesh was a similar material (Tensar Corp., Morrow, Georgia) but with 24.5 x 5.5 mm oval holes; and the nylon netting had 8.7 x 7.2 mm hexagonal holes and was also used for temporary barrier testing (Memphis Net and Twine, Inc., Memphis, Tennessee). See text for descriptions of the other materials.

Material	Height (m)	No. of Shock Wires	No. of Snakes Tested	% of Snakes Retained	No. of Snake-Nights Tested	% of Snakes or Snake-Nights Retained for Best Variant	n for % of Snakes Retained	n for % of Snake-Nights Retained
Poly mesh	1.10	3-5	83	83.3	>350	100	>50	
Tensar mesh	1.10	3-5	151	92.5	>150	100	10	
Nylon netting	1.10	3-5	152	87	>300	100	>50	
Metal mesh	1.32	0	>300		>700	99		114
Thin vinyl	1.15	0	>150		215	63		215
Thick vinyl	1.15	0	40		221	97		221
Thick vinyl	1.52	0	>140		83	100		83

Choosing a Barrier

Through extensive testing on several scales, snake barriers have been shown to be effective solutions for the problem of preventing snake movement into sensitive areas or out of infected zones. Starting in 1997, three of these models have also been tested operationally. The temporary barrier was first used in conjunction with the Tandem Thrust military exercise originating from Guam. It was built by Wildlife Services (U.S. Department of Agriculture) specialists and Air Force personnel, using guidance and assistance from the research team. The metal mesh barrier was installed around the commercial port on Rota, Northern Mariana Islands. It was constructed by a private contractor, with the researchers' guidance and assistance. A version of the masonry barrier was built on Tinian, Northern Mariana Islands, to quarantine building supplies shipped from or through Guam. It was modified by a construction firm contracted by the Voice of America from plans provided by the research team. The researchers hope to construct a landscape-scale operational vinyl barrier in 1998.

Which barrier should be used for what need?

Temporary or permanent barrier? The primary issue in making this decision is the duration of the need. Temporary barriers provide less protection than permanent barriers and require more frequent inspections, but are also less expensive and time consuming to construct. They can be easily transported and may be set up wherever a suitable flat surface is available. Temporary barriers are ideal for short-term projects, but are not designed for continuous use (in large-scale tests of temporary barrier netting; chronic damage from feral pigs, rats, and solar degradation was encountered). If the short term need is recurring (e.g., military exercises staged from the same base or chronic cargo overflows), then a permanent barrier may offer better protection and lower annual costs.

Which permanent barrier? Permanent barriers may be more economical on an annual basis and they provide a higher degree of protection. Long-term protection is likely to be needed in one of three main contexts: 1) large-scale protection of sensitive installations such as airports; 2) small-scale protection of extra-sensitive installations such as cargo-handling facilities; and 3) protection of conservation sites.

Most large-scale transportation facilities in the Pacific, such as ports and airports, are surrounded by chainlink fencing and hard surfaces such as asphalt. This provides a suitable support structure for the metal mesh barrier. The metal mesh barrier is appropriate for situations where vision through the fence is desirable. All barriers must be monitored to prevent the adherence of animal or plant materials that would give purchase to a climbing snake. The researchers predict that the masonry and metal mesh barriers will be relatively more vulnerable to such problems than will the vinyl barrier. Large-scale applications of the metal mesh barrier to chainlink fences around major facilities, such as airports, are unlikely to provide complete protection against snake incursions, if only because the fence's length makes regular careful inspections expensive. Metal mesh barriers are likely to require periodic replacement due to rust, with survival time depending on the grade of fencing used and on the local conditions to which it is exposed. In the Mariana Islands, metal mesh barriers are likely to fail catastrophically during typhoons (=hurricanes). Wind loading during typhoons may also result in destruction of the chainlink fence, with loss of protection for large areas, at a time when repair materials are unavailable and fencing repair services are likely to be overburdened with competing commitments. Furthermore, the loss of physical security at airports can affect the safety of aircraft operations. Therefore, the use of the metal mesh barrier in areas for which moderate-term breaches in protection cannot be tolerated (e.g., high security transportation facilities, endangered species refugia) is not recommended. If intended for sites where future realignment of fences is anticipated (e.g., port will be expanded in five years), the metal mesh barrier may be the preferred choice, as it minimizes the initial cost and, therefore, the value lost through shorter term replacement.

Examples of especially sensitive sites include power stations and cargo handling facilities. Such needs are likely to be both localized and very long-term, and a higher up-front investment in a more durable barrier may generate savings in maintenance costs. For such needs, the masonry or vinyl barriers, which provide the highest protection and durability are recommended. Both of these models may be used in areas where architectural influences should be considered, and both are opaque, affecting sight distances. For rough terrain, most likely associated with protection of endangered species, the vinyl barrier is preferred at present, although the limits of its applicability to rough terrain have not been explored. It may provide adequate protection without the addition of an overhang or electrification. If so, it would be the simplest model and one with the lowest maintenance costs. Once testing is complete, it is believed the vinyl barrier will be the tool of choice for rough terrain applications, as its modular design allows it to be fit to uneven ground, it can be transported in sections into areas not serviced by roads, and barriers made of this material are easily fabricated using hand tools.

Snake barriers provide a practical solution to many snake encroachment problems, and growing uses for them is foreseen in the coming years.

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FERTILITY CONTROL IN COYOTES: IS IT A POTENTIAL MANAGEMENT TOOL?

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ABSTRACT: Fertility control in wildlife is emerging as a potential management tool. Published research on feral horses, deer, rodents, and rabbits suggest an effective agent producing reversible infertility in these species could be developed. Furthermore, anecdotal reports suggest that infertility can be induced in a greater array of species. In this paper, the authors review methods of fertility control being studied for application in wildlife and focus on their studies designed to evaluate the effectiveness of fertility control agents in coyotes (*Canis latrans*). Immunocontraception using porcine zona pellucida (PZP) is currently the most promising method of fertility control in coyotes the authors have studied. This is consistent with results from other species. However, the vital question of whether any fertility control agent can reduce livestock losses due to coyote predation will require more research.

KEY WORDS: *Canis latrans*, coyotes, fertility control, GnRH, immunocontraception, PZP

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INTRODUCTION

The search for alternative methods of managing nuisance wildlife has intensified in recent years. This is largely a result of stricter controls on traditional management techniques (i.e., use of chemicals), an expanding human population encroaching on wildlife habitat, the adaptability of some wildlife species to urban and suburban environments, the inability to manage such populations by traditional methods (e.g., hunting white-tailed deer [*Odocoileus virginianus*] and Canada geese [*Branta canadensis*], and trapping coyotes), and changing public attitudes toward lethal control. An alternative strategy for dealing with nuisance wildlife that has received considerable attention is fertility control. The authors' objectives are to review the current research on fertility control, and discuss some issues that may influence the use of fertility control methods in wildlife management. They also present preliminary results produced by the organizations that contribute to the goal of increasing understanding of reproductive physiology and behavior in carnivores, and producing a contraceptive system, using the coyote as a model.

METHODS OF FERTILITY CONTROL

Fertility control research can be broadly categorized under three general strategies: 1) surgical/chemical sterilization; 2) endocrine perturbation; and 3) immunocontraception. Each method has a unique set of advantages and disadvantages that influences the practicality of use in managing wildlife damage.

Surgical Sterilization

Surgical sterilization has been used successfully in domestic companion animals for many years, and with captive wildlife in zoos and research facilities. The primary advantage of this technique is that one treatment renders the animal permanently incapable of reproducing. While this is an advantage in domestic species and in captive wildlife, permanent sterility is sometimes considered a disadvantage of surgical sterilization for populations of wild animals. Concerns over permanent sterility in wildlife include a loss of genetic information from a population; permanently altered behavior patterns; the impractical implementation in wild populations; difficulties in capture and handling large numbers of animals; anesthesia; post-operative care; and cost of implementation.

While these concerns may be valid, surgical sterilization has been used effectively in several cases to manage some wild populations (Kennelly and Converse 1997). Several populations of feral cats were managed effectively with surgical sterilization (Neville 1983; Neville and Remfry 1984). These examples demonstrated that a wild population could effectively be managed with surgical sterilization when most healthy adults could be captured. Although the initial costs of this control method were high, the authors estimated that long-term costs would be lower than other control methods because only monitoring and periodic castration was necessary.

Bailey (1992) demonstrated that surgical sterility of introduced red fox (*Vulpes vulpes*) onto Alaskan islands occupied by arctic fox (*Alopex lagopus*) could reduce adverse effects on native avifauna. The two fox species are not sympatric and, after nine years, the arctic foxes were extirpated from the islands and only a few red fox remained on one of the islands.

Brooks et al. (1980) and Kennelly and Lyons (1983) demonstrated that surgical sterilization could effectively control reproduction in beaver (*Castor canadensis*). Converse and Kennelly (1994) also successfully applied the technique to Canada geese. However, surgical sterilization was unsuccessful in controlling red-winged blackbird (*Agelaius phoeniceus*) production (Bray et al. 1975). Kennelly and Converse (1997) implied that effective use of surgical sterility is limited to species that are monogomous.

Little research has been conducted on surgical sterilization in wild canids. Mech and Fritts (1993) vasectomized five wolves (*Canis lupis*) and released them in northern Minnesota. They concluded that vasectomized wolves maintained pair bonds and territories, suggesting this method may be effective at reducing predation on livestock. Till and Knowlton (1983) demonstrated that adult coyotes (*Canis latrans*) reduced predation on livestock when the pups were removed from dens. They concluded that, in some situations, predation on livestock was driven by the presence of pups; when adults need to feed pups, they select larger prey items. These studies suggested that if reproduction in wild canids could be controlled while leaving territorial behavior intact, livestock losses could be reduced. This reduction might result if wild canids did not use larger prey sizes to support offspring, and the adults maintained territories, thereby preventing intact canids from immigrating into the area. National Wildlife Research Center biologists are currently testing this hypothesis. During December 1997 and January 1998, wild coyotes from about seven packs in northeastern Utah were captured. Packs were randomly assigned to either a treatment or control group. All animals in treatment groups received either a tubal ligation or vasectomy. Control group animals received a sham surgery, which consisted of the same anesthesia and surgical protocols except the oviducts and vas deferens were left intact. All animals were released where they were captured within 24 hours. Over the next three years, territorial, reproductive, and predatory behavior of these animals will be monitored to determine if surgical sterilization without removal of gonads influences these factors.

Endocrine Regulation

Steroids. Hormonal control and regulation of fertility in vertebrate species has primarily been accomplished through the use of steroids (Kirkpatrick and Turner 1991; Asa 1997). Progestogens and androgens successfully surpress normal ovarian cyclicity in domestic canids and felids, and in captive wildlife. However, use of progestins reportedly increases growth of the uterine lining and, consequently, induces hyperplasia, pyometra, and neoplasia in canids and felids, in addition to mammary development and post-therapy lactation (Asa and Porton 1991). Androgens also have undesirable effects, the most significant being external masculization. These effects, expense, and requirement for regular administration, are reasons steroids are generally considered impractical for use in wild populations.

Melengestrol acetate implants are the most used contraceptive in zoos (Porton et al. 1990). This steroid has also been used in oral forms with varying success (Asa 1997). Experiments to control fertility in coyotes have been conducted using steroid compounds such as diethylstilbestrol, mibolerone, and prostaglandins (Balser 1964). Although oral formulations would make these and other progestins (e.g., medroxyprogesterone acetate, levonorgestrel, megestrol acetate) more suitable for use in wild populations, the side effects previously discussed would still be expected. Additionally, oral presentation of these products could affect non-target species both directly via consumption of the compounds in baits, and indirectly if predators or scavengers consumed animals which had taken steroid-laden baits.

GnRH and Agonists. Recent efforts in endocrine regulation of fertility have focused on gonadotropin-releasing hormone (GnRH). A non-steroidal hormone, GnRH would have the advantage of no secondary toxicity because it is rapidly metabolized into amino acids. Gonadotropin-releasing hormone, a key regulator of reproduction in male and female mammals (Figure 1), is released by the hypothalamus in the brain and travels through a portal blood system to the anterior pituitary at the base of the brain. Gonadotropin-releasing hormone stimulates the anterior pituitary to release lutenizing hormone (LH) and follicle-stimulating hormone (FSH) in both females and males. These hormones subsequently influence the release of progesterone and estradiol in the female, and testosterone and estradiol in the male.

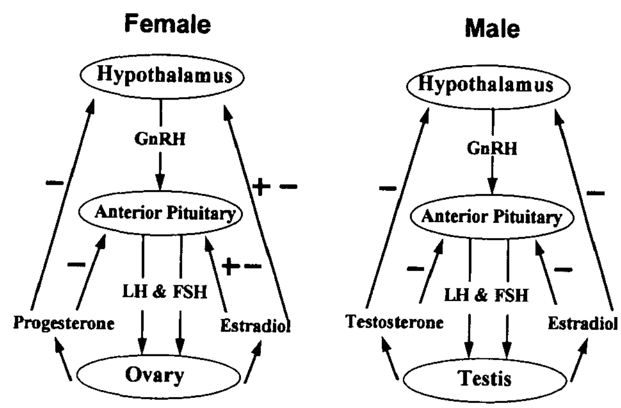

Figure 1. The mammalian hypothalamic-pituitary-gonadal axis in males and females (adapted from Becker and Katz 1997).

Gonadotropin-releasing hormone and its agonists have been used in male Hawaiian monk seals (*Monachus schauinsland*) (Atkinson et al. 1993) and African elephants (*Loxodonta africana*) (Brown et al. 1993). Single injections of GnRH in males of these species decreased blood testosterone levels and, subsequently, aggressive behavior. However, prolonged administration of GnRH in cattle and red deer (*Cervus elaphus*) has resulted in stimulation of both pituitary and testicular function (Melson et al. 1986; Lincoln 1987).

Continuous administration of GnRH has inhibited ovulation in several species due to a negative feedback response by the hypothalamus (Vickery et al. 1989; Herschler and Vickery 1981; McNeilly and Fraser 1987; Montovan et al. 1990). However, Becker and Katz (1995) were unsuccessful in inhibiting LH secretion by the anterior pituitary with continual infusion of an GnRH analog. They suggested more research is needed to determine the usefulness of GnRH as a technique for regulating reproduction. Becker and Katz (1997) suggested that variation in response of the hypothalmic-pituitary-gonadal axis may be due to the choice of agonist, dose, treatment regimen, reproductive status, and species. Furthermore, they point out that the practicality of using GnRH as a contraceptive is dependent on the development of long-acting, time-release agonist that can be delivered remotely. Such an agonist, though, is currently unavailable.

Antiprogestins. Antiprogestins (also called anti-progestogens) are derivatives of cholesterol molecules and have some of the properties of steroid hormones (Dence 1980; Teutsch et al. 1995). These compounds tend to be stable, which allows for oral delivery without degradation and loss of function in the digestive tract. It also prolongs the duration of stability in bait materials, an important consideration for field delivery systems. There are few reports regarding the use of antiprogestins in canids. When used in domestic canines, termination of pregnancy without negative side effects was reported (Concannon et al. 1990; Sankai et al. 1991). Baulieu et al. (1987) published the first papers dealing with the antiprogestin mifepristone (RU-486). This compound has since been used in a variety of species as a contragestive with up to 80% effectiveness following a single oral dose (Brogden et al. 1993). However, when used in conjunction with prostaglandins, the success rate reaches 100% (Brogden et al. 1993).

The authors are currently evaluating the effectiveness of mifepristone and an analog (RTI3021-003; Research Triangle Institute, North Carolina) as contragestive agents in coyotes. Initial results suggest that RTI-003 used alone is not an effective contragestive agent in coyotes. However, the effectiveness of RTI3021-003 in combination with misoprostol, a prostaglandin, and mifepristone combined with misoprostol is also being evaluated.

Immunocontraception

Immunocontraception uses an individual's own immune system to disrupt reproduction (Figure 2). This is accomplished through the administration of a vaccine that results in the production of circulating antibodies or cellular immune effector cells in the target animal. Unlike vaccines developed to protect animals from infectious agents, contraceptive vaccines must trigger an immune response to self-antigens. Thus, an individual's immune system must be trained to target antigens it normally would not.

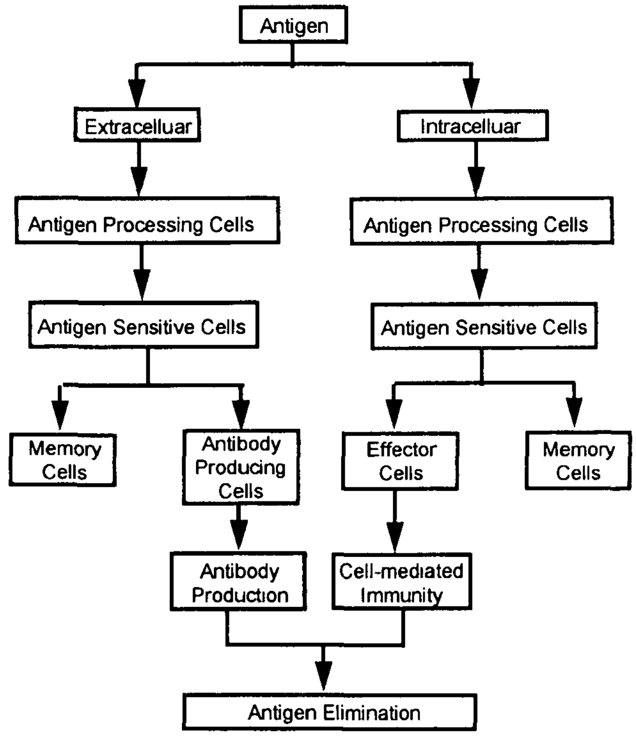

Figure 2. Essential features of the immune response (adapted from Tizard 1996).

Contraceptive vaccines studied to date can be classified as hormone-based vaccines and gamete-based vaccines. Hormone-based vaccines attempt to illicit an immune response against an individual's reproductive hormones. Studies have evaluated vaccines targeting GnRH, LH, and FSH (Thau et al. 1987; Mougdal 1990; Becker and Katz 1997).

Active immunization against GnRH has had some success in numerous domestic species (Clarke et al. 1978; Adams and Adams 1986; Awoniyi et al. 1987; Safir et al. 1987; Ladd et al. 1988; Baile et al. 1989; Adams et al. 1993). Circulating GnRH antibodies produced by immunization bound GnRH after it was released from the hypothalamus and before it reached the pituitary. Antibody-bound GnRH was ineffective at stimulating the release of LH and FSH, which resulted in impaired reproductive function. The effectiveness of these immunizations at suppressing reproductive function was positively correlated to the GnRH antibody titer (Lincoln et al. 1982; Safir et al. 1987; Baile et al. 1989).

Little research has been conducted on GnRH vaccines in wildlife. Studies on red deer (*Cervus elaphus*) have had mixed results (Lincoln et al. 1982; Ataja et al. 1992; Freudenberger et al. 1993). Ataja et al. (1992) found only a light suppression of LH and no reduction of testosterone levels. Alternatively, Lincoln et al. (1982) observed a significant decrease in testosterone combined with testicular atrophy and premature casting of antlers.

Becker and Katz (1997) suggested that variable results from GnRH immunizations may result from differences in carrier proteins used in vaccines, timing of primary immunizations relative to the reproductive season, and variability of individual animal immune responses to the vaccines.

The authors have conducted preliminary research on the use of GnRH vaccines to prevent reproduction in coyotes. They vaccinated five male and five female coyotes with 300μg of GnRH conjugated with keyhole limpet hemocyanin (KLH). The coyotes were boosted twice with 200μg injections of the GnRH-KLH vaccine at monthly intervals. Two of the females developed high antibody titers to GnRH and did not produce high levels of progesterone. Thus, it was assumed that these females did not ovulate or ovulated but did not maintain corpora lutea, which produce the progesterone required to maintain pregnancy. The remaining three females did not produce high GnRH antibody titers, or the antibodies were produced too late to prevent ovulation and a rise in progesterone. Of the five males vaccinated with GnRH, two developed high antibody titers, which resulted in a decrease of testosterone to levels observed prior to the breeding season. Three males had low antibody levels and either normal or only moderately reduced testosterone levels. It appears from this limited study that GnRH vaccines have some potential to control reproduction in coyotes; however, more research would be needed to evaluate the efficacy of such a vaccine. The problem of delivering such a vaccine in the absence of an orally active form seems particularly daunting.

The second group of contraceptive vaccines studied to date are gamete-based vaccines. These vaccines are designed to affect spermatogenesis, oocyte maturation, fertilization, and trophoblast development. Of these, vaccines directed at oocyte maturation, and specifically the zona pellucida (the glycoprotein matrix surrounding the mature mammalian egg), have received the most attention in wildlife (see reviews by Warren et al. 1997; Turner et al. 1997; Kirkpatrick et al. 1997). However, little research has been conducted on the use of such vaccines in predators.

The authors initiated research to evaluate gamete-based vaccines for fertility control in coyotes. In December 1995, female coyotes were injected with 300 μg of PZP, and boosted with 200 μg on PZP in January 1996. This initial study resulted in a reduction of mean litter size from 3.5 pups among control females, to 1.3 pups for vaccinated females. In December 1996, the same female coyotes were boosted again with 45 μg of PZP. This single, low dose boost was performed to evaluate if an annual boost would effectively keep litter sizes reduced. The results of this second year of research suggested that annual boosters of PZP were effective in maintaining reduced litter size; mean litter size during the second year was 3.8 pups/female and 2.6 pups/female for the control and PZP animals, respectively.

Although their earlier research on PZP demonstrated it was an effective immunocontraceptive for reducing coyote litter size, the authors initiated a second study to determine if more frequent boosting with PZP prior to the breeding season could eliminate litters entirely. In December 1997, they vaccinated five female coyotes with 300μg of PZP and boosted with 200μg four and six weeks later. In this experiment, females were euthanized and necropsied 30 days after the last observed breeding date. All control females were pregnant and the mean number of fetuses/females was 5.8, compared to zero fetuses in PZP vaccinated females. Thus, the PZP vaccine can be an effective immunocontraceptive in coyotes. The authors are currently conducting research that will elucidate the mechanism through which PZP reduces fertility, and will conduct research designed to develop an orally deliverable form of PZP.

CONCLUSIONS

The most effective means of resolving wildlife-human conflicts in many situations is to reduce wildlife populations by shooting, poisoning, or trapping. However, as the human population expands into wildlife habitat, lethal control options become limited and controversial. Thus, there is an increasing need to develop non-lethal control strategies that can be integrated into damage management programs.

Presently, relatively few cost-effective, non-lethal control options are available to managers. Fertility control could provide an effective addition to control programs. However, many hurdles must be overcome before fertility control becomes a viable alternative. These include, but are not limited to, the development of contraceptive agents that are orally deliverable, species specific, reversible, have few side-effects, and are cost effective (Sanborn et al. 1994).

Is fertility control a potential management tool for coyotes? Current research suggests that it has possibilities. Studies conducted to date on immunocontraception suggest it has the potential for at least reducing litter size in coyotes. Further studies on antiprogestins will assess the value of these compounds in reducing litter size. Will litter size reduction significantly alter predatory behavior of coyotes on livestock? If productivity in a local population of coyotes is reduced, or eliminated, but the loss of livestock in the area is not significantly reduced, then a fertility control program would not be an effective management tool. The authors' research with surgically sterilized coyotes should provide an answer to this key question.

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SOCIAL AND BIOLOGICAL ASPECTS OF NON-NATIVE RED FOX MANAGEMENT IN CALIFORNIA

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ABSTRACT: Since the late 1800s, non-native red foxes have been introduced in California for fur farming and fox hunting. Dispersal, population growth, and extensive translocations by humans have aided the expansion of the non-native fox population throughout many of the lowland and coastal areas of the state. Since the 1980s, non-native red foxes have been recognized as predators of a number of endangered species. Trapping and euthanizing non-native red foxes have been used as methods to protect these endangered species, but have been opposed by some members of the public. Opposition by animal rights groups to red fox trapping and euthanization has significantly influenced the management actions and policies of wildlife agencies. Red foxes are among the wildlife species commonly recognized in our culture; however, their historical use as a commodity and a game animal, and their impact on several endangered species, make them a difficult and controversial species to manage. Both fox biology and the public place great demands on wildlife agencies to develop new, proactive management strategies for non-native red foxes.

KEY WORDS: California, introduction, management, non-native red fox, social, *Vulpes vulpes*

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INTRODUCTION

Non-native red foxes (*Vulpes vulpes*) were introduced at many locations in California in the past 130 years. Population growth and dispersal from these points of introduction have resulted in an almost continuous distribution throughout the lowland and coastal areas west of the Sierra Nevada and southern Cascade Range. Their presence attracted little attention until the mid 1980s, when state and federal wildlife agencies were forced to manage foxes as a means of protecting endangered species. Management of non-native red foxes, predominantly by trapping and euthanization, began after they were implicated in the decline of the endangered light-footed clapper rail (*Rallus longirostris levipes*), California clapper rail (*Rallus longirostris obsoletus*), and California least tern (*Sterna antillarum browni*) in several coastal California refuges (U.S. Fish and Wildlife Service and U.S. Navy 1990; U.S. Fish and Wildlife Service 1990; Zembal 1992). Red foxes had become abundant in these coastal marsh refuges. Continual control of red foxes at Seal Beach National Wildlife Refuge (NWR) coincided with increasing counts of light-footed clapper rails (Zembal 1992), and with increased nesting success of California least terns at Bolsa Chica Ecological Reserve (E. Burkett, pers. comm.). While trapping and euthanization have been opposed by some members of the public as management methods, alternative methods such as relocation of captured foxes to zoos or to other states have not been successful; zoos did not need or want additional red foxes, and wildlife officials in other states would not accept non-native red foxes.

Fox management as a means of protecting clapper rail and California least tern populations has received much attention; however, little attention has been focused on fox predation on other endangered species. The western snowy plover (*Charadrius alexandrinus nivosus*), San Joaquin kit fox (*V. macrotis mutica*), salt marsh harvest mouse (*Reithrodontomys raviventris*), and Belding's savannah sparrow (*Passerculus sandwichensis beldingi*) are among some of the threatened or endangered species vulnerable to red fox predation in California. The native Sierra Nevada red fox (*V. v. necator*), a state-listed threatened species, may be vulnerable to non-native red foxes through the effects of interbreeding, disease transmission, and resource competition (Lewis et al. 1995). However, the distribution, prey relations, and population characteristics of the non-native red fox are biological aspects that are often overshadowed by a number of human traditions, events, and cultural issues that have influenced their management in California. A number of historical and recent events were summarized to demonstrate the importance of social issues and biology in shaping non-native red fox management.

A HISTORY OF HUMAN INVOLVEMENT

Non-native red foxes were brought to California largely for fur production and recreation. The appearance of non-native red foxes in northern California in the late 1800s suggested that foxes were brought from the midwest on the Transcontinental Railroad, which was completed in 1869 (Roest 1977). Sleeper (1987) reported the importation, captive breeding, and release of non-native red foxes in southern California from 1905 to 1919, specifically for fox hunting. Presumably the same is true for northern California where red foxes were hunted as early as the 1880s (Grinnell et al. 1937;

Hanson 1944). However, red foxes have been used as a biological control for mammalian pests (Schoen 1970), and it is possible that extensive campaigns in the late 1800s to control California ground squirrels (*Spermophilus beecheyi*) (Grinnell and Dixon 1918) prompted the introduction of non-native red foxes.

Breeding red foxes in captivity for pelt production (i.e., fox farming), became an industry across the United States in the early 1900s (Ashbrook 1923), and arrived in California around 1920 (U.S. Dept. Agric. 1922; Ashbrook 1923; Anonymous 1926). Red fox breeding stock and pelts (predominantly the silver phase) sold for thousands of dollars in the early 1900s, prompting the spread of the industry throughout North America (Jones 1913). In California, the industry was building in the early 1930s, when there were at least 30 fox farms (Anonymous 1930), and was still growing in 1942 when there were around 125 (Vail 1942). The 1940s and 1950s were the heyday of fox farming; thereafter, the industry began to decline and no farms are known to be in operation in the state today. Releases of undesirable foxes and the escape of others were not uncommon occurrences on fox farms (Aubry 1984). The number of farms and their distribution throughout the state reflect the potential for both accidental and intentional introductions (Lewis et al. 1995).

While fox farming and hunting were the major means of historical introductions, more recent introductions appear to be quite different. Red foxes are among animals kept as pets (Leslie 1970). Disenchantment with unruly pet foxes has resulted in their release, which probably contributed to the occurrence of non-native red foxes in many of California's urban areas (Lewis et al. 1993). Similarly, residents of some urban areas have captured non-native red fox pups but have had poor success domesticating them. Unwanted, injured, or rescued non-native foxes are also taken to wildlife rehabilitators and caretakers. Some wildlife rehabilitators have released them in areas not previously occupied by non-native red foxes in California (Estrada 1989; Lewis et al. 1995). As a means of dealing with problem animals, animal-control officials in some municipalities and counties of California have also translocated non-native red foxes. Animal rights activists have also played a role in some red fox introductions, as one animal rights' organization has taken credit for illegally liberating 265 foxes from fur farms in North America in 1995 to 1996 (see internet web page http://envirolink.org/alf/pub/fnsup/fnsup.html). And recently in some southeastern states, demand for fox-hunting opportunities has prompted the illegal marketing, transporting, and attempted containment of red foxes in large hunting enclosures (Poten 1991; Davidson et al. 1992).

BIOLOGICAL ASPECTS OF MANAGEMENT

Non-native red foxes are now widely distributed throughout many of the lowlands and coastal areas of California west of the Cascade range and Sierra Nevada (Lewis et al. 1993). This extensive distribution makes range-wide management difficult. Consequently, management has focused on localized problems (e.g., fox predation on endangered birds in a refuge), with the understanding that this management may be necessary on a long-term basis because foxes may regularly disperse to the problem area (Lewis 1994). Non-native red foxes are effective predators of native prey species because these species lack specific defenses against foreign predators. Ground-nesting birds (e.g., California and light-footed clapper rails), especially those that nest in colonies (e.g., California least tern and western snowy plover), are particularly vulnerable to red fox predation and surplus killing (Kadlec 1971; Kruuk 1972; Maccarone and Montevecchi 1981; Golightly et al. 1994). Many unlisted species of birds, mammals, and insects are also vulnerable to red fox predation (Golightly et al. 1994).

In southern California, urban encroachment has reduced the amount of habitat for the light-footed clapper rail and California least tern, concentrating them in small refuges located on the coast. These refuges, as well as parks, golf courses, agricultural fields, airports, and cemeteries, provide habitat for red foxes within the urban matrix (Lewis et al. 1993). These areas provide suitable habitat for red foxes, in part, because they are generally too small or isolated for an abundance of coyotes (*Canis latrans*) which prey on and compete with red foxes. In the absence of coyotes, non-native red foxes can become abundant within the urban environment (U.S. Fish and Wildlife Service and U.S. Navy 1990; Lewis et al. 1993). Available corridors (e.g., flood channels, railroads, and power lines) within the urban matrix can aid in dispersal of red foxes to wildlife refuges on the coast, perpetuating the need for fox control (Lewis 1994). The U.S. Fish and Wildlife Service and U.S. Navy (1990) considered coyote reintroduction as a means of protecting endangered birds from red foxes and other small carnivores at Seal Beach NWR. However, before any coyote reintroductions were conducted, a number of coyotes apparently recolonized Seal Beach NWR and nearby Bolsa Chica Ecological Reserve (Bolsa Chica) on their own accord; consequently, a number of these coyotes were radio-collared as part of an ecological study (Romsos, in prep.). Monitoring has also shown that the number of red foxes has declined in Seal Beach NWR and Bolsa Chica to the point where few tracks are seen and fox control efforts have not been necessary for several years (C. Knight, USDA Wildlife Services, Sacramento, CA, pers. comm.). Future monitoring will indicate whether these developments are long-term phenomena.

Fox control efforts at coastal refuges have often incorporated the use of padded leg-hold traps. To prevent potentially depredating foxes from learning to avoid leg-hold traps, Lewis et al. (1993) used cage traps to capture non-native red foxes as part of a field study in urban southern California. As red foxes are shy of new structures and odors in their environment, catching foxes, especially adults, is difficult and time consuming when using cage traps. Foxes would have to become accustomed to the traps through prebaiting, which involved offering bait inside and outside a trap while the trap door was wired open. When tracks indicated that a fox fully-entered the trap to get the bait, the trap door would then be unwired so that it would shut when an animal triggered the trap. Prebaiting could take anywhere from one to ten or more days. During one 10-month period, prebaiting accounted for five times as many nights as trap-nights (341 vs. 67; Lewis et al. 1993), significantly increasing the effort expended to capture a fox. Trapping foxes with leg-hold traps does not involve introducing a visible structure to a fox's environment (i.e., a relatively odor-free trap is covered with a thin layer of soil); its objective is to present nothing new to a fox other than an attractive bait or scent. Consequently, leg-hold trapping has been more effective for capturing foxes than cage trapping (Table 1). Coyotes are also more effectively captured with leg-hold traps than with cage traps (Los Angeles Co., Dept. Agric. Comissioner, unpubl. data).

SOCIAL ASPECTS OF MANAGEMENT

Among animals that play a part in American culture, the red fox has a rich history and broad appeal. Red foxes are found in animated films, television documentaries, internet web pages, calenders, business and product names, children's literature, and wildlife art. Beautiful, sly, crafty, mischievous, and wary are terms commonly used to describe red foxes. These characteristics, as well as the red fox's place in our culture, make them appealing to pet owners, animal rights activists, trappers, fox hunters, fur buyers, wildlife photographers, and the public in general. Unfortunately, many endangered (and consequently obscure) species do not evoke the same sentiment, creating a dilemma for some members of the public who must weigh endangered species protection against trapping and euthanizing red foxes.

In California, red foxes have been managed via hunting, trapping, fur-farming, and predator control by wildlife management agencies. These activities are frequently opposed by animal rights groups, and these groups have influenced red fox management actions and policies. In the late 1980s, animal rights groups opposed to fox trapping and euthanization at Seal Beach NWR won a court order requiring the federal government to prepare an environmental impact statement (EIS) to address potential management alternatives. During preparation, and following completion of the EIS (U.S. Fish and Wildlife Service and U.S. Navy 1990), capture and euthanization were continued as a means of controlling red foxes. However, a number of animal rights groups continued to protest ongoing control efforts. Realizing that animal rights' activists were also likely to protest planned red fox control efforts at the San Francisco Bay NWR, the U.S. Fish and Wildlife Service prepared an environmental assessment of management options to protect endangered species on that refuge. Although there was opposition by animal rights groups, capture and euthanization were used on this refuge to reduce the number of red foxes (U.S. Fish and Wildlife Service 1990). Most animal rights opposition to predator management has been done through lobbying politicians and wildlife management agencies, or through organized protests in the presence of invited news media. However, verbal abuse, harassment, threats, interference with activities and traps, and a gun shot have been directed at field personnel that were involved with capturing foxes at one southern California site (R. Baker, Calif. State Polytech. Univ., Pomona, pers. comm.; Witmer and Baker 1996).

In the Spring of 1991, an extension of California State Highway 55 was about to be opened for commuter traffic in Costa Mesa, California. A construction worker at the highway site alerted the media that the traffic on this freeway extension would kill a family of red foxes that lived in a den in the freeway embankment. At that time, California Department of Fish and Game (CDFG) had an endangered species protection policy at nearby Bolsa Chica that included trapping and euthanizing red foxes. While this strategy was unpopular, it was viewed as the most effective option because no zoo or state would accept non-native foxes. Television newscasters derided CDFG for taking the initial stance of allowing the foxes to remain in place (i.e., risking them to traffic). CDFG

Table 1. Capture data for red foxes when using cage traps and leg-hold traps in California, 1987 to 1997. Since capture rate is positively correlated to density, leg-hold trapping data was limited to the first episode (first four to ten days) of trapping at a trapping locale when fox densities were greatest. Fox densities during this first episode were most comparable to the densities of foxes in areas where cage trapping occurred.

Trap Type	County	Time Period	Trap-Nights	Fox Captures	Capture Rate[a]	Source
Cage trap	Orange	18 months	511	17	3.33	Lewis et al. (1993)
Padded leg-hold	Orange	4 days	68	8	11.76	Calif. Dept. Fish & Game, unpubl. data
Padded leg-hold	Alameda, Santa Clara	10 days	160	17	10.63	T. Elliot, USDA, Wildl. Serv., San Diego, unpubl. data
Padded leg-hold	Los Angeles	5 days	48	13	27.08	R. Baker, Calif. State Polyt. Univ., unpubl. data

[a]Capture rate = (fox captures/trap nights) x 100.

chose this stance because the same pair of adult foxes (the adult male was radio-collared) had denned and had successfully raised a litter of pups on a freeway embankment near traffic the year before (Lewis et al. 1993), and because CDFG did not typically rescue non-native red foxes. Alternatively, CDFG could have trapped and euthanized them, consistent with their policy at Bolsa Chica, although this was not their preferred option. Television broadcasters portrayed CDFG as a heartless bureaucracy and urged the public to call CDFG and the Governor and give their opinion. The pressure generated by the public prompted the Governor to direct CDFG to capture and deliver the foxes to two zoos which had offered space for the red foxes to help resolve the controversy. An adult female and her six pups were captured. One zoo received considerable media attention by holding a contest to name two of the freeway fox pups. This controversy demonstrated the sensitivity of the public toward red foxes, the ability of the news media to exploit it, and the need for developing new, proactive management strategies.

In 1996, an animal rights group opposed the capture and euthanization of non-native red foxes at Shoreline Park in Mountain View, California. This city park is located adjacent to the San Francisco Bay NWR, which supports several endangered species including the California clapper rail and salt marsh harvest mouse. A survey indicated that red foxes had become more abundant at Shoreline, and these foxes were approaching golfers and park employees for food (City of Mountain View 1997). Shortly after the survey, a number of foxes became sick and park employees became concerned about health risks to themselves and the public. The foxes had contracted sarcoptic mange and, consequently, died of the disease. The city considered alternatives for managing non-native red foxes given the growing number of red foxes, their proximity to endangered species populations, the risk of disease transmission to park visitors, an animal rights group's opposition to capturing and euthanizing foxes, and the inability of park personnel to manage foxes. Maintaining the status quo, and capture and euthanization of foxes at the site were two of the three options considered (Harvey and Associates 1996). An animal rights group proposed a third option: after being treated for diseases and sterilized, foxes would be kept in a fox refuge where they would be fed at feeding stations. Regular applications of coyote urine along the designated, unfenced perimeter of the refuge was suggested by the animal rights group as a means to contain the foxes and prevent them from preying on nearby endangered species. After a review of the proposals by an independent consulting group (Harvey and Associates 1996), the City of Mountain View developed a long-term policy for non-native red foxes that involved capturing and euthanizing red foxes unless they could be placed in homes where they would not be released (City of Mountain View 1997).

In 1996, several trapping and sportsmen's groups proposed a hunting and trapping season for non-native red foxes. The season was intended to provide additional hunting and trapping opportunities to the public, but it could also act to control the spread of non-native red foxes and reduce their population in the state (Calif. Fish and Game Comm. 1996). This proposal, which was supported by CDFG, presented a means of managing the non-native red fox population across much of its range. The California Fish and Game Commission decided to delay voting on the proposal until a later date (R. Pelzman, Calif. Fish and Game Comm., pers. comm.), effectively delaying a possible red fox season. Members of sportsmen's groups attributed the postponement to the lobbying efforts of animals rights groups (R. Aiton, Calif. Trappers Assoc., pers. comm.).

In 1997, a group of animal rights organizations proposed a statewide ballot initiative that would prohibit the use of body-gripping traps for recreational trapping, commercial trapping, and endangered species protection efforts in California (Initiative coordinator, Attorney General's Office, State of California, pers. comm.). Proponents of the proposed initiative collected enough signatures for the initiative to be included on the November 1998 ballot. This initiative, if passed, will undoubtedly have a significant effect on endangered species protection efforts. Similar ballot initiatives were passed in Arizona, Colorado, Massachusetts, and New Jersey.

In some urban and suburban areas, red foxes are fed by the public (Golightly et al. 1994). This feeding can maintain unusually high densities of foxes in and near areas where people, their pets, and endangered wildlife occur (Lewis et al. 1993; Golightly et al. 1994). Although disease transmission from red foxes to humans or their pets has not been documented in California, the potential for this transmission exists, especially in urban areas where fox densities are greatest. Sarcoptic mange, a contagious mite-infestation observed in canids, has been found in several urban fox populations in California (Lewis et al. 1993; Harvey and Associates 1996), reflecting the potential for disease transmission to domestic dogs (Stone et al. 1972). Rabies is another disease threat that red foxes present (Wandeler 1980). Given the density of red foxes in some urban areas and their proximity to humans, health officials and wildlife managers need to consider potential management options should rabies become an issue.

CONCLUSIONS

Attitudes toward red foxes have changed dramatically in California over the last 130 years. Red foxes were first viewed as a commodity and as a game species. More recently, they have been viewed by some as a non-native predator of endangered fauna and by others as an animal with inherent value that should not be managed or harmed by humans. These differing views have led to conflicts among some of the public and the agencies charged with wildlife management. While non-native red fox management in California may represent a unique situation, similar conflicts in other regions may arise where red foxes adapt to urban areas or where they are introduced in the future. Past events indicated that proactive strategies were necessary for managing non-native red foxes and should include: 1) greater consideration given to protecting other special status species from predation; 2) maintaining current assessments of red fox distribution and density, especially in urban areas; 3) preventing introductions and translocations; 4) developing management strategies that are effective at regional and range-wide scales; 5) preparing for endangered species protection efforts without the use of leg-hold traps; 6) preparing plans to prevent or manage fox-transmitted disease epidemics; and 7) improving communication with the public about fox management issues. Several documents have been published that explain some of these issues to the public (Burkett and Lewis 1992; Jurek 1992; CDFG 1994); however, non-native red fox management, among other important wildlife management issues, warrants much more attention.

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THE MANAGEMENT OF HOUSE MICE IN AGRICULTURAL LANDSCAPES USING FARM MANAGEMENT PRACTICES: AN AUSTRALIAN PERSPECTIVE

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ABSTRACT: During 1995 to 1997, the efficacy of early tactical management of mouse populations in a project based on grain-growing farms in Victoria, Australia was examined. Farmers modified their management practices of crops (at sowing, harvest, and land preparation), and managed habitats on the boundary of cropped land (such as fencelines) and around farm buildings. One management practice examined was the effect on mouse populations of controlling weeds along margins of crops. On sites where farmers slashed or sprayed weeds in early spring, there was a comparative reduction in the abundance of mice in late summer compared to untreated sites.

KEY WORDS: House mouse, control, Australia, management, ecologically-based pest management

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INTRODUCTION

Populations of the introduced house mouse (*Mus domesticus*) periodically outbreak and cause severe damage to crops in agricultural areas of Australia (Singleton and Redhead 1989; Mutze 1991; Caughley et al. 1994). Farmers use rodenticides, such as strychnine or zinc phosphide when mouse densities are high (this is called "crisis management"). In recent years, governments have provided temporary registration for such rodenticides, but often too late to prevent significant damage to crops (Mutze 1989, 1993b; Brown et al. 1997). In 1995, 250,000 ha of cropping land were aerially baited with strychnine (Fisher 1996).

An alternative to crisis management is to take early preventive management through modifying farming practices. The aim is to slow the rate of growth of mouse populations so that densities are maintained below levels which cause significant economic hardship to farmers (this is called "tactical management").

Farming systems in the grain belt of Australia have changed markedly in the past 15 years. This is in response to the need for greater efficiency, the falling real value of farm produce, the wider cropping options available to the industry, and the desire for farmers to manage their land for a more sustainable future. "Conservation farming" techniques aim to prevent soil erosion, minimize use of water and labor while being a more economically viable and environmentally benign system. Modifications to traditional farming systems incorporate an increased frequency of cropping, a more diverse range of crops, extended cropping seasons, stubble retention, minimum tillage, and direct drilling. These factors, however, provide favorable conditions for mice through providing high quality food for longer periods and less disturbance of nesting sites (Mutze 1993a; Griffiths 1993). It is likely that these practices are responsible for an increase in the frequency of mouse plagues since 1980 (Singleton and Brown 1998).

In Australia, particular habitats (such as the uncropped zone beside fences) have been identified as important for the survival and breeding of mice in agricultural regions (Newsome 1969; Singleton 1989; Mutze 1991; Chambers et al. 1996). However, little has been done to examine the effects of modifying habitats on mouse abundance. Indeed, there has been only one large-scale manipulative study in which Whisson (1996) examined the effect of habitat change on the population dynamics of the canefield rat (*Rattus sordidus*) in sugarcane crops of northern Queensland. Comparisons were made between areas where minimum tillage and conventional practices (pre-harvest burning of sugarcane and intensive cultivation) were conducted. In the two treatments there were differences in survivorship and breeding performance of the rats, but not in the level of crop damage (Whisson 1996).

Research over the past decade has provided a good understanding of how mouse plagues develop in the cereal-growing regions of southeastern Australia (see Singleton 1997 for review). During 1995 to 1997, the efficacy and practicality of early tactical management of mouse populations in cereal-growing regions in Victoria, Australia was examined, by combining the knowledge of scientists and farmers. The scientists provided knowledge of the biology and habitat use of mice and the farmers provided practical recommendations on possible farm management actions that could modify how mice use the agricultural landscape. A project advisory panel was also formed, consisting of farmers and government agricultural officers, that identified the degree of mouse control required, when and where to best implement control, and provided advice on extension of results (Singleton and Brown 1998).

In this paper the effect of one of the farm management practices is reported; controlling plant growth along fences in early spring by spraying or slashing grassy weeds before they set seed. Fencelines are considered a significant habitat for mice because they provide an undisturbed habitat which is not cultivated and where growth of weed species occurs. The effects of this treatment were assessed by monitoring mouse populations in the following summer.

METHODS

Two regions from the cereal growing area of northwestern Victoria, Australia were used for this project (Mallee and Wimmera). Both regions have a Mediterranean climate, with hot summers and predominantly winter rainfall. The topography is flat to gently undulating. The mean annual rainfall is 452 mm in the Wimmera and 336 mm in the Mallee. Crops are only grown in winter and spring, and are mainly cereals (wheat, barley, oats, and rye), grain pulses (chickpeas, field peas, lentils, and lupin) and oilseed (canola). Farmers in the Wimmera implement a continuous cropping cycle (cereal-legume-cereal or cereal-oilseed-cereal), whereas farmers in the Mallee implement a three year crop rotation which consists of a winter cereal/pulse crop, pasture, and bare fallow.

Wimmera

Twenty-five fencelines from four farms were selected. Each fenceline used in the study was 200 m in length and was separated by at least 200 m. The amount of available plant cover and food supply for mice was reduced along treatment fencelines (n=13). This was achieved by farmers either slashing plant-growth within two meters of the fences using a mechanical slasher attached to a tractor, or by spraying plant growth within two meters of fences with herbicides to prevent seed-set of weed species. Treatments were applied in early spring (September 1996; n=9) or late spring (October 1996; n=4). Vegetation along untreated fencelines (n=12) was allowed to grow unhindered.

Mouse abundance (number of mice caught per 100 trap nights, adjusted using the frequency-density transformation [Caughley 1977]) was assessed by setting 20 traps, each spaced 10 m apart along each fenceline for two consecutive nights. Trapping was conducted in October 1996 (Spring) and in February 1997 (Summer).

Plant biomass samples were taken from five quadrats (0.1 m^2) along each fenceline. Quadrats were positioned every 45 m, 0 to 200 mm from the base of the fence. All species of plants in each quadrat were recorded, harvested using grass shears, placed in paper bags and oven dried at 40°C for three days. Plant biomass was collected at the same times that trapping was conducted. The availability of seed was not measured.

Mallee

Twenty-four fencelines from four farms were selected. Each fenceline used in the study was 200 m in length and was approximately 200 m apart from each other. Fencelines were visually assessed according to plant biomass (high or low). Fencelines with high plant biomass had vegetation >150 mm in height, with >80% ground cover (n=13), whereas fencelines with low plant biomass had vegetation <150 mm in height, with sparse ground cover and included chemical (spraying) or mechanical (slashing) treatment (n=11). The methods for trapping and assessment of plant biomass were the same as those used in the Wimmera.

Statistical Analysis

After log transforming mouse abundance (to improve the validity of the constant variance assumption), a residual maximum likelihood (REML) analysis was conducted using biomass and the spring mouse abundance as a covariates using the statistical software, Genstat 5, Release 3.2 (Lawes Agricultural Trust, Rothamstead Experimental Station, England). Least Significance Difference (LSD) tests were then performed (using approximate "t" tests).

RESULTS

Wimmera

There were significantly fewer mice caught along sprayed fencelines that along unsprayed fencelines (approximate $t = 1.29$; d.f. = 20; $P < 0.05$) (Figure 1). The timing of spraying was not important. The abundance of mice along fencelines that were sprayed early was significantly different to untreated fencelines ($t = 1.44$; d.f. = 19; $P < 0.05$), similarly for late sprayed and untreated fencelines ($t = 0.91$; d.f. = 19; $P < 0.05$). Neither biomass nor spring mouse abundance were significant factors in the covariance and were excluded from the analysis.

Mallee

There was no apparent relationship between the height of biomass in spring and the abundance of mice in summer ($t = 0.52$; d.f. = 22; $P < 0.05$) (Figure 1).

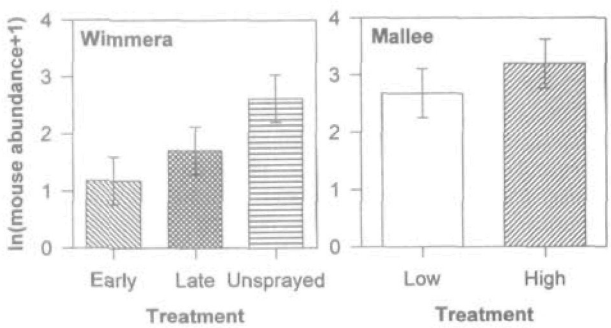

Figure 1. Mean mouse abundance (logarithm of adjusted trap success, ± standard error) in summer for each fenceline treatment for the Wimmera and Mallee.

DISCUSSION

Spraying of plant growth along fencelines in early spring in the Wimmera significantly reduced the abundance of mice in late summer. Weed species along fencelines provide a high quality food source to mice and can trigger breeding in early spring (Bomford 1987; Tann et al. 1991). Spraying reduces seed-set of weed species, and may delay the start of the breeding season of mice.

Further work is required to examine the effect of fenceline management on the damage caused in adjacent crops the following year.

In the Mallee, height of biomass was examined rather than how the vegetation was treated. Based on the findings, it was not recommended that farmers slash or spray their fencelines. However, it may be that small plants, although providing sparse ground cover, still produce high quality seeds that may be important for breeding of mice. Future research needs to examine the effect of spraying and slashing on seed production by grasses, and the subsequent response of mouse populations.

The lack of cover of weed species on areas either sprayed or slashed along fencelines may increase the vulnerability of mice to predation. The presence of avian predators can regulate the growth of mouse populations when they are in low numbers (Sinclair et al. 1991), but this relationship requires further study.

A potential problem of slashing or spraying weed species along fencelines in spring is the likely increase in germination and growth of noxious summer weeds. The removal of winter grasses reduces competition for resources for summer weeds. If this is the case, farmers may need to spray or slash in early spring and again in summer, or use a combination of slashing and spraying at different times. The benefit-cost of this strategy needs to be examined.

The management of plant growth along fencelines is just one action farmers can take to reduce the impact of mice. Other actions have been suggested for different growth stages of crops (sowing, growing, and harvest) and for different types of management (routine, preventive, and crisis) (Singleton and Brown 1998). These actions include livestock grazing immediately after harvest, smoothing the ground at sowing (to cover furrows which then makes it more difficult for mice to locate sown seed) and baiting at key times of the year (at the onset of breeding in early spring).

The present study examined one set of actions for managing mice for specific farm systems. Different responses by mice to these actions were found for the two farming regions. Further research is required to determine which management actions for mice are appropriate for particular farming systems. One interesting system would be the irrigated summer cropping areas, where channel banks provide good mouse habitat and there is little grazing by stock of stubbles.

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MANAGING MOUSE PLAGUES IN RURAL AUSTRALIA

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ABSTRACT: The frequency of mouse plagues in grain-growing areas of Australia has increased since the advent of conservation farming practices. The increase has been particularly marked on the Darling Downs in Queensland where the frequency has trebled. Broadscale monitoring is undertaken by the government to provide a general forewarning of plague. However, the authors found, from a questionnaire to farmers, that the incidence and timing of plagues is highly variable across the Downs. It is apparent that farmers need to monitor the numbers of mice on their properties at regular intervals if they are to undertake preventive management. Bait cards (pieces of paper soaked in canola oil) were tested as a method for on-farm monitoring. The average amount of each card eaten was significantly correlated with the density of mice, but because of the scatter of the data the authors recommend that the cards be used in conjunction with other signs of mice such as evidence of crop damage or of active holes and runways in stubble. Zinc phosphide bait was found to be a highly effective rodenticide if used at a time when food was scarce. If the bait receives registration, it would be a valuable tool to control mice in crops, especially prior to flowering. On the basis of these results, it was concluded that effective management of mice could best be achieved by minimizing food supply in stubble by efficient harvesting, regular monitoring, and by strategic baiting and stubble management when necessary.

KEY WORDS: bait card, monitoring, mouse plague, mice, *Mus domesticus*, zinc phosphide

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INTRODUCTION

The house mouse (*Mus domesticus*) was introduced to Australia around the time of European settlement and has since spread across the whole of the continent. Most of the time its numbers are low but, when conditions are favorable, populations can irrupt to "plague proportions"—that is, high enough numbers to be a pest. When these irruptions occur in agricultural areas, they cause serious economic, environmental and social stress (Caughley et al. 1994).

Over most of this century, plagues have been relatively rare events occurring on average about once every 8 to 10 years in a particular district. Until recently, they have tended to follow droughts, and drought-breaking rain was considered the primary trigger for an irruption (Saunders and Giles 1977; Singleton 1989). However, the frequency of plagues has increased since the 1980s (Singleton and Brown 1998). The increase is attributed to the advent and progressive adoption of conservation agriculture, particularly stubble retention which provides continuous shelter and protection for mice between cropping phases.

The increase has been particularly marked on the Darling Downs in Queensland where a plague has occurred on average every three years since 1980 (Singleton and Brown 1989). The Darling Downs is a premier grain-growing region. Farming is intensive and a farm may have three plantings per year (winter, spring and summer) depending on rainfall and soil moisture profiles. The winter crop is typically wheat or barley; spring and summer plantings are principally sorghum and cotton, but corn, sunflower, and legumes are also grown.

Mouse numbers have been monitored on a 32 km transect, across the Central Downs since 1976 and used to provide an early warning of outbreaks. However, the authors have noticed that the monitoring does not predict all outbreaks on the Downs. In some areas, particularly to the east of the transect, plagues may occur in different years. It has also been noticed that not all farmers in an area in a given year are affected. In an attempt to quantify this variability, a questionnaire was sent to farmers asking them when they had experienced mouse problems in crops in the last five years (Donkin and Caughley 1998).

At the same time, the apparent variability in plague occurrence and severity across the Downs led the authors to question how farmers could best manage mouse outbreaks. If the broadscale monitoring and prediction of plagues is only partially satisfactory in warning farmers of the likelihood of a plague, on-farm monitoring by farmers themselves will be necessary.

At present, farmers use a number of methods to track mouse abundance over time. The most common method is general surveillance. By noticing the number of mice seen when harvesting and working paddocks, in sheds and around silos, and when driving at night, farmers are aware of the trends in numbers on their property. When numbers increase to such a level that mice begin to be a problem around the house and sheds, farmers lay traps and/or bait. Both trapping and baiting provide them with a quantitative estimate of density if numbers caught or amount of bait used are recorded.

For tracking numbers in fields, the most common technique being promoted is "bait cards" which are squares of paper soaked in canola oil and pegged out overnight in crops or other habitat. The extent of nibbling on the papers provides an indication of mouse abundance (Ryan and Jones). Bait cards were widely used by farmers during broadscale baiting campaigns in recent plagues in Victoria, South Australia, and Queensland. In Victoria and South Australia, baiting was recommended by government agencies if, on average, 20% of each bait card was eaten. In Queensland, the threshold was set at 10%. However, these threshold figures have not been equated to mouse densities.

The use of bait cards for regular monitoring in fields is as yet not widely adopted. The authors believe that farmers are more likely to use the method if it can be related to mouse densities, and for that reason they have endeavored to establish this relationship.

The next problem that needed to be addressed was how farmers can control mice if their monitoring indicates numbers are increasing. To date, farmers have had limited options to control mice by baiting. No rodenticide is registered for broadacre application in cereal crops in Australia. During the plagues in 1993 and 1995, strychnine was given temporary approval. However, no maximum residue level (MRL) has been assigned for strychnine by Australian authorities or by the International Codex Committees on Pesticide Residues and Residues of Veterinary Drugs in Food. When no MRL is assigned, it is by default set at zero. Since it is impossible to prove zero contamination because all assay techniques have a lower limit of detection, the use of strychnine is no longer permitted.

In 1997, temporary approval was given by the National Registration Authority for Agricultural and Veterinary Chemicals (NRA) for field trials and for broadscale use of zinc phosphide bait during irruptions in several areas of Australia. Because an MRL exists for the bait's breakdown product, phosphine, it would be possible to register the product if it were found to be successful in controlling mice and have no untoward environmental or occupational health impact.

To evaluate zinc phosphide bait, field trials were conducted with the bait in different crop stages. On the basis of these results, the authors make recommendations on how strategic baiting could be incorporated into mouse control if the product receives registration. At the time of writing, the NRA has received an application from the manufacturer for the registration of the bait for broadacre application in cereal, oil and legume crops. If the bait is registered, farmers will then have the option of strategic baiting when their monitoring indicates mouse numbers are high.

This paper reports on the results of the three-pronged approach into the management of mouse plagues on the Darling Downs. First, the authors evaluate the pattern of mouse plague irruptions on the Darling Downs in Queensland; second, they evaluate the use of bait cards for monitoring mouse numbers; and third, they evaluate the efficacy of zinc phosphide as a broadacre rodenticide. The findings are then incorporated into recommendations for on-farm management.

METHODS

Evaluating the Pattern of Recent Mouse Plague Irruptions on the Darling Downs

Downs Monitoring—Mouse numbers have been monitored at 47 sites along a 32 km transect on the Darling Downs since 1976. The monitoring was undertaken approximately monthly between 1976 and 1986 by Cantrill (1992). In 1989, the Department of Lands (now Department of Natural Resources) re-instigated the monitoring and has trapped at varying time intervals since. The sites encompass the range of soil types used for cropping on the Downs. Eighteen of the 47 sites are within roadside verges; 28 sites are on farms and have varied in crop type and stage over seasons; and one site is in pasture. On each trapping occasion, 20 break-back mouse traps baited with bacon are laid at each site in a line at 8 to 10 meter intervals in the late afternoon and collected early the next morning. Traps that have fired, but have not caught a mouse are subtracted from the total number of traps set (940) to give an adjusted number of traps; % trap success is then calculated as:

$$\% \text{ trap success} = \frac{\text{No. mice caught} \times 100}{\text{Adjusted no. traps}}$$

Questionnaire—To evaluate the spatial and temporal heterogeneity of mouse plagues across the Downs at the farm level, a questionnaire was mailed to members of the Queensland Grain Growers Association on the Downs. They were asked whether they had experienced mouse problems in crops in the last five years (1992 to 1996 inclusive), and to rate the problem in each of the seasons as minor, moderate, or severe. Full details of the questionnaire are given in Donkin and Caughley (1998).

Evaluating Bait Cards as a Monitoring Technique

Bait cards are 10 cm x 10 cm squares of white paper which are soaked in canola oil and pegged out overnight in a line of 10 cards at a spacing of 10 meters. The cards are placed within crops, stubbles, and any other area where mice may be harboring. For each site, the number of squares eaten on each card is counted and the average number for all the cards is calculated to give "% bait card eaten" for that site (Figure 1).

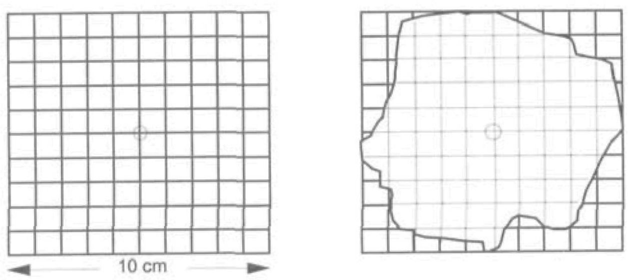

Figure 1. Diagram of bait cards. To estimate amount eaten, the number of squares remaining are counted or the nibbled bait card is superimposed on an unused card as shown on the right, and the number of squares visible on the lower card are counted and subtracted from 100. The card here is about 27% eaten.

Bait cards were used in combination with three other methods of estimating mouse numbers on different occasions over the past year. The three other methods were: population estimation by mark-recapture; % trap success with live capture traps; and % trap success with break-back traps. The live traps used were Elliott Type E traps which were baited with rolled oats and peanut butter, and usually set in a grid of 6 by 8 traps at 10 meter intervals. Traps were set for one or two nights, depending on whether the aim was an index of density (i.e., % trap success) or a population estimate. Break-back traps were used as described above under Downs monitoring.

Evaluating Zinc Phosphide as a Broadacre Rodenticide

The bait used was manufactured by Animal Control Technologies Ltd. and contained 2.5% active ingredient mixed with sesame oil and applied to irradiated wheat grains. The maximum permissible application rate under the field trial permit was 1 kg per hectare. Five trials were run using ground application, four in sorghum stubble and one in soybean stubble, using a granular applicator mounted on a fertilizer spreader. One trial was run in a wheat crop (pre-flowering) using aerial application.

The effectiveness of the bait was measured by determining the number of mice by mark recapture immediately before baiting and then three nights after baiting. In the soybean stubble, an indication of the amount of alternative food was obtained by counting the number of soybeans within ten 1 m^2 quadrants.

RESULTS

The Pattern of Recent Mouse Plague Irruptions on the Darling Downs

In the 10 years between 1977 and 1986, the trap success exceeded 20% between March and July in six of the years, and 30% in two of these six years (Cantrill 1992) (Table 1). In the nine years of government monitoring since then (1989 to 1997), the trap success has exceeded 20% in four of the years, and exceeded 30% in three (Figure 2). The number of plagues (n = 6) between 1980 and 1997 is the same as that reported by Singleton and Brown (1998), but there is a slight difference in the years in which these plagues occurred [Singleton and Brown (pers. comm.) included an outbreak in 1991 that was not apparent in the results from the monitoring; conversely, the monitoring detected an outbreak in the Central Downs in 1997 that they did not include].

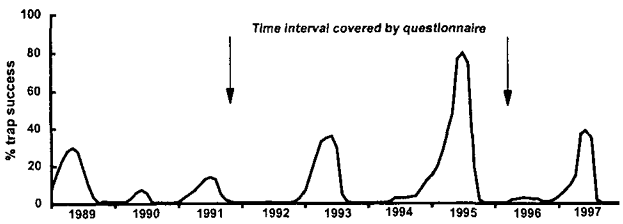

Figure 2. Trend in % trap success recorded on the Downs transect between 1989 and 1997. The time interval covered by the questionnaire encompasses two peaks in density—one moderate in 1993 and one extremely high in 1995.

Table 1. Maximum % trap success (gs) recorded each year between 1977 and 1986 by Cantrill (1992) and between 1989 and 1997 by government monitoring on the Darling Downs transect.

Year	Maximum %ts
1977	11.1
1978	22.9
1979	14.6
1980	**33.6**
1981	4.1
1982	23.2
1983	20.4
1984	25.1
1985	**35.4**
1986	12.6
1987	n.d
1988	n.d
1989	**28.4**
1990	7.1
1991	**11.7**
1992	0.8
1993	**33.8**
1994	2.6
1995	**77.4**
1996	3.0
1997	36.3

The bold figures denote the plague years in Singleton's and Brown's calculation of plague frequency between 1980 and 1997 (Singleton and Brown, pers. comm.). n.d.= no data.

The differences in plague occurrence in Table 1 is indicative of the spatial and temporal heterogeneity of irruptions of mice across the Downs, and is further evidenced in the results of the questionnaire. From the Downs monitoring, the authors were expecting that the questionnaire would show that farmers experienced crop damage from two plagues—1993 and 1995. Instead they found, first that 22% of the respondents had had no problem with mice over the five years (Table 2). Second, half of the farmers had experienced only one plague. Third, when one specific outbreak was looked at, namely the major plague that occurred on the Downs in 1995, only 43% of respondents were affected. While half of these ranked the damage they suffered as severe, the other half ranked it as moderate. Even more surprising was the result that some farmers reported a problem when the Downs monitoring indicated mouse numbers were low (particularly in 1996).

It is clearly evident that farmers need to monitor mice on their own properties if they are to implement control measures to limit mouse damage.

Table 2. Number of plagues experienced over the last five years by Darling Downs respondents to the questionnaire (n=204).

No. of Plagues Experienced	% of Respondents
0	22
1	53
2	23
3	2

Note: broadscale monitoring has indicated there were two outbreaks of mice in that time (see Figure 2.)

Evaluation of Bait Cards

As yet the authors have insufficient data matching % bait card eaten and population estimate, since bait cards have been laid on only three occasions when mark-recapture was undertaken. More data (n=21) are available comparing % bait card taken and % trap success with Elliott traps. Therefore, to obtain a relationship between % bait card eaten and population size, a relationship was first derived (Figure 3) between % trap success with Elliott traps and population size from mark recapture, namely:

$$\ln(\text{mice per ha}) = 1.34 \ln(\text{trap success}) - 0.22$$

that is, $\text{mice per ha} = 0.8 \text{ trap success}^{1.34}$

Using this relationship, the authors calculated the estimated density of mice from % trap success with Elliott traps at the 21 sites, where they had both % trap success with Elliotts and % bait card eaten. The following relationship was then derived between % bait card eaten and estimated density ($r^2 = 0.64$):

$$\text{estimated density (mice per ha)} = 8.0\,(\%\text{ bait card eaten}) + 69$$

At the previously recommended threshold for baiting, namely 10% bait card eaten, the equation indicates the number of mice would be around 150 per hectare. While this density is possibly an appropriate threshold (as yet there is no relationship between density and crop damage), the variation in the data around this value is high. The authors are concerned that farmers could be misled by a low bait card take. For instance, on two occasions a low % bait card eaten was recorded when the % trap success with Elliott traps was high (Figure 4). The high variability when the bait card take is below 10% is even more obvious in the data obtained on bait card take and % trap success with breakback traps (Figure 5).

The reason for the low bait card take at high mouse densities is unknown. It may simply be that the amount of card eaten is a combination of mouse numbers and the amount of other food available, but to date the authors have not been able to establish a significant relationship between crop type and stage and % bait card eaten. Much more data are needed on factors influencing the amount of bait card eaten before this index can be used reliably as a means of monitoring mouse numbers or as a threshold for strategic baiting.

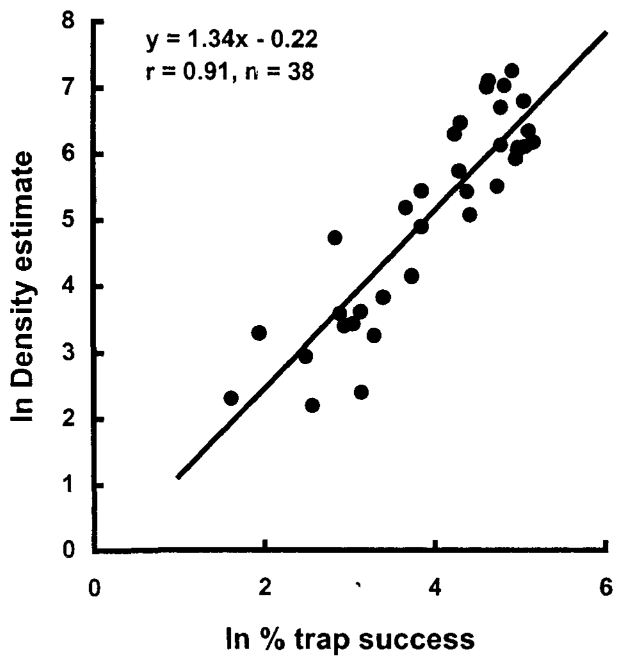

Figure 3. Relationship between % trap success with Elliott traps and density (mice per ha) estimated from mark-recapture.

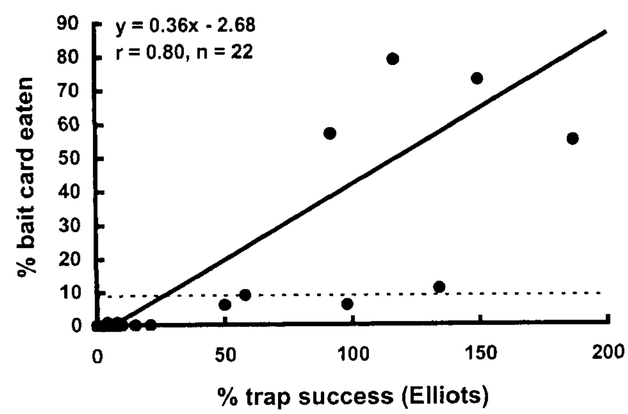

Figure 4. Relationship between % bait card eaten and % trap success with Elliott traps.

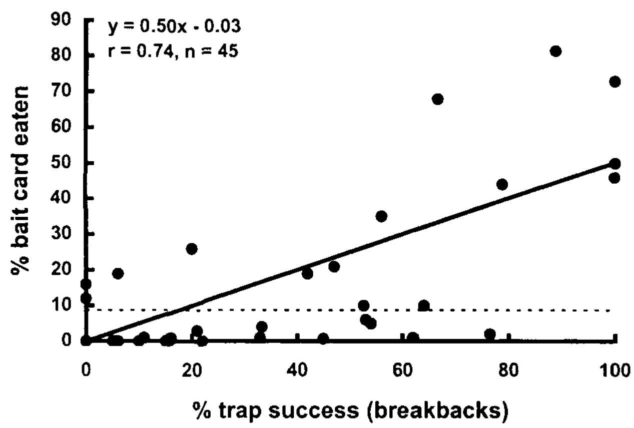

Figure 5. Relationship between % bait card eaten and % trap success with breakback traps.

Evaluation of Zinc Phosphide Bait as a Broadacre Rodenticide

The effectiveness of the zinc phosphide bait varied markedly between trials (Table 3). The worst result was achieved when the bait was applied immediately after harvest. There could be two explanations for this failure. First, the pre-baiting estimate may have been an underestimate if the mice were disturbed by the harvester. However the % trap successes on the two nights of pre-baiting were respectively 98% and 103%—mice were definitely active above ground. The second reason is that too much alternative food was available. The crop was badly affected by sorghum ergot which produces a sugary exudate on the seed heads. It is likely that the mice were feeding on the exudate as well as the sorghum grain. The ergot exudate was still present on secondary stalks left behind after harvesting and there was cracked grain in the trash; both would have competed with the bait as a food source.

At the other end of the spectrum, the reduction achieved was highly satisfactory. In both the pre-flowering wheat crop and one of the old sorghum stubbles, the number of mice remaining after baiting was low enough to curtail impact for several months. At the remaining two sites, the availability of alternative food was reasonably high. The sorghum crop had been severely lodged and the farmer had not used crop lifters when harvesting. Heads on the ground still contained seed four months later, and the number of mice was high. Even though a 64% reduction was achieved, the number of mice remaining was still high enough to cause significant damage if they dispersed into adjacent crops when the seed supply in the sorghum was spent. In the soybean stubble, the result was similar.

DISCUSSION

The results highlight a number of problems for managing mouse irruptions. First, the evaluation of the pattern of mouse plagues across the Downs in recent years indicates the high level of spatial and temporal variation in irruptions and how important it is that farmers undertake monitoring on their own properties at regular intervals. This spatial and temporal heterogeneity in plagues has been reported in all plague-affected areas in Australia (Mutze 1991; Singleton and Redhead 1989; Chambers et al. 1996), and an effective means of on-farm monitoring is needed in all the grain-growing areas.

On the Downs, the most important times to monitor mice are in summer and autumn. Mice begin breeding in spring and, if conditions are favorable, numbers will continue to rise through summer. The peak density usually occurs between March (late autumn) and July (mid winter). For this reason damage is usually most severe in maturing summer crops and in early plantings of winter crops.

Bait cards are a simple means of monitoring and it was found the % eaten was significantly correlated with estimated density of mice and with % trap success. However, while a high % bait card eaten indicated high mouse numbers, the converse was not necessarily so. Setting 10% bait card eaten as a recommended threshold for baiting may prevent farmers from taking action when mouse numbers are in fact at a level that will lead to extensive crop damage. Further research may improve the accuracy of the bait card technique, but in the meantime the authors suggest that a low bait card take is confirmed by other signs of mouse activity, such as number of holes and runways in stubble, and evidence of damage in crops. If farmers are uncertain, it is recommended that they use traps such as breakback traps to determine the density of mice.

In addition to monitoring, farmers need to employ management practices that will limit the build up of mice. Brown et al. (1998) found that good farm hygiene, particularly reduction of weeds and grasses along fencelines to reduce seed set and harbor for mice, reduced the severity of an outbreak. Generally the farms on the Downs are well managed; the majority of farmers mow grassy verges and keep areas around buildings and grain storages relatively clean. Also, because land use is intensive on the Downs, the extent of grassy areas is small. The major habitat for mice is within crops and stubble. To control the numbers of mice in stubble, the best routine management practice available to farmers is to harvest efficiently. At present, there is insufficient attention paid to minimizing grain left behind at harvest. For example, crops that are badly drought affected are not always harvested. Crop lifters are not always used to harvest crops with significant lodging. Diseased crops (e.g., with sorghum ergot) are not dried off and harvested quickly. In each situation, mice are provided with a source of food which prolongs the suitability of the habitat.

There will be times, despite good farm hygiene and efficient harvesting, that mouse numbers will be high in stubble. Farmers can then work or slash the stubble to reduce the amount of cover for mice without necessarily losing the advantage of erosion control through its retention. If zinc phosphide bait receives registration as a broadacre rodenticide, strategic baiting may also be an option. But strategic baiting will principally be a tool for controlling mice in crops since there are no alternative management options (except grazing off the crop or cutting it for hay). Because these field trials showed that

Table 3. The results of the field trials on the effect of zinc phosphide bait on mouse numbers per hectare.

Crop Type and Stage	Food Availability	Pre-baiting Density	Post-baiting Density	Reduction	Comments
Wheat —booting	very low	573	31	95%	Mice feeding on embryo heads in tillers
Sorghum —stubble	very low	442	41	91%	4 months post harvest
Sorghum —stubble	moderate	1,317	478	64%	4 months post harvest, but crop severely lodged
Soybean —stubble	high	896	544	39%	3 weeks post harvest; soybeans 8 g m^2
Sorghum —stubble	very high	1,106	1,134	-3%	2 days post harvest; crop badly affected by ergot

the best results are achieved when alternative food is scarce, farmers need to check for mice in their crops and undertake baiting (if necessary) before flowering commences. If mice are not detected before seed fill, baiting is still an option, but warn that if numbers are very high there may still be enough mice remaining to cause damage to the crop. If this is the case, the best option is to harvest the crop as early as possible.

At present, the authors are advocating baiting as a strategic control measure in crops, but it is hoped that in the long term there may be a form of biological control. Research is underway at the Vertebrate Biocontrol Centre on controlling mice through virally-vectored immunocontraception (Chambers et al. 1997). These experiments are proceeding well and may be at the field testing stage within the decade. In the meantime, the authors believe that an integrated approach of good farm hygiene, especially clean harvest, on-farm monitoring, and strategic baiting when mouse numbers are high will reduce the burden of mice for Australian grain-growers.

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AN OVERVIEW OF RECENT GROUND SQUIRREL BAIT REGISTRATION RESEARCH SUPPORTED BY THE CALIFORNIA BAIT SURCHARGE PROGRAM

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ABSTRACT: The California Department of Food and Agriculture Rodent Bait Surcharge Program is actively funding studies to develop and register safe, effective and practical ground squirrel baits. Under this program, Genesis Laboratories has conducted eight studies since 1994 designed to fulfill registration requirements for existing baits and to develop new baits. Areas of research include field efficacy, application methods and rates, non-target hazards, and residue loads in animal and plant tissues. Existing diphacinone and chlorophacinone treated oat groat baits have proven to be effective in controlling the California ground squirrel. Applications of these baits to alfalfa crops did not result in quantifiable residue loads. Preliminary studies found bromethalin treated oats may be effective against the California ground squirrel. Chlorophacinone treated cabbage bait was not effective against Belding's ground squirrel.

KEY WORDS: rodenticides, California Ground Squirrel, Belding's Ground Squirrel, diphacinone, chlorophacinone, bromethalin, efficacy, residues

Proc. 18th Vertebr. Pest Conf. (R.O. Baker & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 1998.

INTRODUCTION

In 1990, the California state legislature passed a bill authorizing the county agriculture commissioners to collect a surcharge of 50 cents on each pound of vertebrate pest control material sold. Monies generated by this fee are used to fund research to fulfill registration requirements of existing vertebrate pesticides, and to explore new vertebrate management products and methods.

Genesis Laboratories has conducted eight research projects under this program since 1994. Six of these projects were designed to fulfill data requirements needed to obtain Section 3 EPA registration of existing anticoagulant bait formulations. Two field efficacy studies of novel baits or formulations for ground squirrel control have also been conducted.

For many years diphacinone and chlorophacinone treated oat groat baits for ground squirrel control have been produced by various counties under a 24C (Special Exemption) label maintained by the California Department of Food and Agriculture (CDFA). Both 50 ppm and 100 ppm formulations with each active ingredient (a.i.) are currently produced. The 100 ppm products are now labeled for spot baiting only. The 50 ppm formulations are approved for spot baiting and in bait stations.

One requirement of the USEPA Pesticide Assessment Guidelines (Section G: 96-12) is that rodenticides be at least 70% effective against the target species when used according to label directions. Field efficacy tests were conducted of these existing anticoagulant baits as well as a bromethalin-treated oat bait. In addition, a chlorophacinone-treated cabbage bait was tested against Belding's ground squirrel. Non-target hazards and bait stability were evaluated in conjunction with the efficacy testing.

In addition, crop residues of the diphacinone and chlorophacinone oat baits were evaluated on alfalfa, where voles (*Microtus* spp.) are the primary target species.

FIELD EFFICACY AND NON-TARGET HAZARDS

Diphacinone-Treated Oat Baits

In 1994, field efficacy tests were conducted of the Rodent Bait Diphacinone Treated Grain oat groat baits to control the California ground squirrel (*Spermophilus beecheyi*). The results were presented at the 17th Vertebrate Pest Conference (Baroch 1996).

To briefly summarize, the baits (50 parts per million [ppm] and 100 ppm) were found to be effective in controlling *S. beecheyi* in spot baiting and bait station applications. Squirrel carcasses found on the surface of treated plots averaged about one per acre. There were a number of non-target kills from direct bait consumption by rodents and rabbits. There were no cases of secondary poisoning observed, although various avian scavengers consumed poisoned squirrel carcasses. The baits were found to decompose rapidly when applied by spot baiting.

Chlorophacinone-Treated Oat Baits

In 1995, studies were carried out using the Rodent Bait Chlorophacinone Treated Grain oat groat baits in 0.005% and 0.01% a.i. concentrations to control the California ground squirrel. The study design followed that used for the diphacinone treated oat bait conducted the year before, as described in Baroch (1996). Both concentrations of the baits were applied by spot baiting. In addition, the 0.005% bait was applied in bait stations. Field efficacy, tissue residue loads, non-target hazards, and bait degradation rates were investigated. The studies were conducted on rangeland at the San Juan Experimental Range near Fresno, California.

Each bait concentration was applied by spot baiting to five replicated plots. Ground squirrel activity on a central area of approximately 2.5 acres in each plot was evaluated before and after application of the baits. In addition, squirrel activity on five untreated control plots of approximately 2.5 acres each was evaluated. A direct index for estimating activity, visual counts, and an indirect index, active burrow counts, were used to evaluate the bait efficacies.

Spot baited plots were treated every other day for four applications immediately following the pre-treatment censusing. Bait was replenished only as needed on each occasion after the first application. The 0.005% bait was applied at a rate of 10.0 pounds per acre. The 0.01% bait was applied at a rate of 9.4 pounds per acre.

The 0.005% a.i. bait was applied on two plots in PVC plastic bait stations for 24 days, starting immediately after the pre-treatment censusing. Bait stations were checked every third day and bait was replenished as needed to maintain a continuous supply. The bait was applied at a rate of approximately two pounds per bait station. Bait stations were placed at approximately 75 foot intervals near active burrows.

Consumption on the treated plots varied from 16.9 to 18.8 pounds per acre. Regular carcass searches were made of all treated plots and surrounding areas. Carcasses of ground squirrels and non-target species were collected. Whole carcass tissues of 10 ground squirrels retrieved from plots in each treatment were analyzed for chlorophacinone residues. Non-target carcasses were retrieved and examined for evidence of test substance ingestion.

On spot-baited plots, squirrels were exposed to the test substances for 12 to 13 days between pre-treatment and post-treatment censusing. Squirrel activity on the plots treated with the 0.005% bait decreased 84.3% according to visual counts and 85.3% according to active burrow counts. Squirrel activity on plots treated with the 0.01% bait decreased by 92.4% using visual activity counts and 78.0% using active burrow counts. Activity reductions were not significantly different statistically between the two bait concentrations.

On bait station plots, squirrels were exposed to the test substances for 24 days between pre-treatment and post-treatment activity counts. Bait efficacy was 93.3 to 100.0% according to the visual index and 89.4 to 90.0% according to active burrow counts. A total of 86 dead ground squirrels (1.21 carcasses/acre treated) were found on the plots spot baited with 0.005% bait. A total of 78 dead ground squirrels (1.07 carcasses/acre) were found on the plots spot baited with the 0.01% bait. Carcasses of six other rodents and lagomorph species were found on the spot baited plots. Necropsies confirmed test substance exposure in some, but not all, non-target species found.

Twenty-five (25) dead ground squirrels (0.77 carcasses/acre) were found on the bait station plots. Carcasses of five other rodent, avian, and herptile species were also found.

No secondary poisoning cases were observed. Turkey vultures (*Cathartes aura*) found and consumed dead squirrels on the treated plots. In some cases they eviscerated the carcasses, leaving behind the entrails which contain the highest concentration of the active ingredient.

Analysis of whole carcass tissue residues in squirrels recovered from spot baited plots found mean residue loads of 0.19 mg of chlorophacinone in squirrels exposed to the 0.005% bait and 0.62 mg of chlorophacinone in squirrels exposed to the 0.01% bait. Analysis of whole carcass tissue residues in squirrels recovered form bait station plots found mean residue loads of 0.162 mg of chlorophacinone in squirrels exposed to the 0.005% bait (n = 10).

Both baits were analyzed and found to be within certified limits before being applied in the field. Analysis of test substance samples exposed in simulated spot baiting applications for nine days found the 0.005% (nominal) bait had degraded to 0.0035% chlorophacinone. The 0.01% (nominal) bait degraded to 0.0078% chlorophacinone when exposed for the same period.

Analysis of samples of the 0.005% bait showed the bait was stable when exposed to field conditions inside bait stations for 24 days.

Chlorophacinone-Treated Cabbage Bait

In the early spring of 1996, a trial was conducted to evaluate the potential of chlorophacinone-treated cabbage bait to control Belding's ground squirrel (*Spermophilus beldingi*) in alfalfa fields in northern California. This species can occur at very high densities, and yield reductions in alfalfa/grass crops of up to 61% have been documented (Sauer 1976). Some populations of this species have historically been reluctant to accept grain based baits (Wright 1982).

Succulent carriers such as chopped cabbage and dandelions have been used effectively in the past, with compound 1080 (sodium fluoroacetate) as the toxicant. Acceptance of these succulent baits is good in early spring when the population has just emerged from hibernation and other food resources are limited. By late spring, when green vegetation is available, bait acceptance declines.

Since compound 1080 is no longer available, chlorophacinone was tested on fresh chopped cabbage as an alternative. Preliminary small plot trials by CDFA personnel indicated that it might be feasible to control the squirrels with one or two relatively heavy applications of chlorophacinone treated cabbage. Because of the expenses and labor involved in preparing and applying such a bait, it was felt that more than two applications would be prohibitively expensive for growers. Accordingly, the study was designed to compare the efficacy of a single heavy application or two lighter applications at a two-day interval. Experience with compound 1080 treated chopped cabbage and with chlorophacinone treated oat groat baits used to control *S. beecheyi*, suggested that a total baiting rate of about 10 to 12 pounds/acre might be sufficient. Fifteen (15) test plots were established in northern Modoc County in March 1996. Squirrel activity on the plots was determined using visual counts and closed burrow counts prior to bait applications. Bait was prepared just before application by hand mixing 200 pound lots of freshly chopped cabbage treated with 0.28% Rozol (chlorophacinone) Mineral Oil Concentrate (LiphaTech, Inc., Milwaukee, Wisconsin). The target concentration was 0.005% a.i., or 50 parts per million (ppm). The actual concentration of a.i. as determined by laboratory assay was 43.6 ppm.

Bait was applied by crews walking the plots and spreading bait on the ground near active burrows. Five plots received a single application, which averaged 11.94 pounds/acre. Five plots were treated with two lighter applications at a two-day interval, with an average application rate totaling 15.67 pounds/acre. Five additional plots served as untreated controls.

Bait consumption began almost immediately. Most of the bait from both treatment regimes was gone within 24 hours of application. Dead squirrels with signs of anticoagulant poisoning began appearing on the surface within three days of the initial applications.

Plots were searched daily for carcasses. This area is along a major migration route for raptors moving north in the spring, including many golden eagles (*Aquila chrysaetos*) and bald eagles (*Haliaeetus leucocephalus*).

Forty-five (45) poisoned ground squirrel carcasses were found on the plots receiving a single bait application. A total of 81 poisoned ground squirrel carcasses were found on the surface of plots receiving two bait applications. Tissues were analyzed from 10 whole squirrel carcasses recovered from each type of treatment plot. Carcasses from plots receiving one application carried a mean residue load of 0.078 milligrams (mg) of chlorophacinone. Carcasses from plots receiving two applications carried a mean residue load of 0.126 milligrams (mg) of chlorophacinone.

In spite of good bait acceptance and the presence of poisoned squirrels on the surface, efficacy was very low for both treatments. When corrected for changes on the control plots, efficacy ranged from 0 to 13% according to both activity indexes.

Either the amount of toxicant or the pattern of applications were not sufficient to control these test plot populations. A higher concentration of bait, or perhaps a pulsed baiting approach, or both, may be required to give adequate control with this toxicant.

Buffer zones of about 100 meters were baited around the activity census plots. Wide-ranging movements by the squirrels may have confounded the results. A few radio-collared squirrels in this study were found to travel great distances in a short time. One individual, a male, moved 1,065 meters from the capture site in one day, then was back at the capture site the next day.

It is recommended that in future studies plots be blocked by treatment type. Plots receiving different treatments should be widely separated, rather than randomly assigning treatments to nearby plots as was done in this case. Treated buffers should be extended as far as is practicable. Finally, the requirements of the visual activity index method (see Fagerstone 1983) used in this study were difficult to meet due to the very unsettled weather which is typical in Modoc County in the early spring. The use of radio telemetry to monitor efficacy is suggested.

Bromethalin-Treated Oat Baits

In the spring of 1996, a trial was conducted with bromethalin-treated oat groats to evaluate the efficacy against *S. beecheyi*. The trial was conducted on rangeland in the eastern Sierra Nevada foothills near Porterville, California. Bromethalin is a promising candidate as a field rodenticide because it does not require repeated applications, and is unlikely to cause nontarget secondary poisoning.

Bromethalin is an acute rodenticide which causes death by uncoupling oxidative phosphorylation in the central nervous system. The LD_{50} ranges from 2.01 to 8.13 in laboratory mice and rats. The compound also acts as an appetite suppressant. Therefore, after the initial exposure, no more feeding takes place. Death typically occurs in two to three days if a lethal dose has been consumed. Recovery from consumption of sub-lethal doses is possible. Because of the mode of action and the small amount of bait consumed, there appear to be few secondary poisoning hazards (Jackson et al. 1982).

The field applications were made in May 1996. Because there was no previous information on necessary dose levels for ground squirrels in the wild, baits were formulated at two widely different concentrations. Nominal concentrations of 0.01% and 0.10% bromethalin-treated oat groat baits were formulated at the Fresno County Agricultural Commission bait mixing facility in Fresno, California. The field trial was conducted in Tulare County, California. Bait concentration analysis was performed by PM Resources, Inc., Bridgeton, Missouri. Tissue residues in recovered squirrel carcasses were analyzed at Genesis Laboratories, Inc., Fort Collins, Colorado.

The baits were applied to 10 plots ranging in size from 11.0 to 13.9 acres. Each bait concentration was applied to five plots. Ground squirrel activity on a central area of approximately 1.7 acres in each plot was evaluated before and after application of the test substances. In addition, squirrel activity on five untreated control plots was evaluated. A direct index of activity, visual counts, and an indirect index, active burrow counts, were used to estimate the bait efficacies.

The baits were applied in 3-inch diameter "T" shaped PVC bait stations placed at approximately 75 foot intervals. The 0.01% bait was consumed at rate of 1.8 pounds per acre. The 0.10% bait was consumed at a rate of 0.8 pounds per acre.

Squirrels were exposed to the baits for 12 to 13 days before post-treatment censusing began. Squirrel activity on the plots treated with the 0.01% bait decreased 60.4% according to visual counts and 37.3% according to active burrow counts. Squirrel activity on plots treated with the 0.10% bait decreased by 64.5% using visual activity counts and increased by 20.5% using active burrow counts.

Squirrel activity on the untreated control plots decreased 30.3% using visual counts and 59.5% according to active burrow counts. Activity decreases on the control plots were attributed to very hot weather during the post-treatment census period. Efficacy calculations for treated plots were corrected for the decreased activity on control plots. Based on analysis of variance, visual activity on treated plots was significantly different from that on the control plots. Visual activity changes were not significantly different between the two treatments. Analysis of active burrow counts only found significant differences between the 0.10% a.i. treated plots and the control plots.

The author believes actually efficacy may have been above the 60 to 65% levels indicated by visual counts. Some squirrels on treated plots were fitted with radio transmitter collars to facilitate retrieval of carcasses. Twenty-one (21) of 27 radio-collared squirrels were found dead on the treated plots within five days of bait placement. Efficacy in this group was 78%.

Regular carcass searches were made of all treated plots. Fourteen (14) dead ground squirrels were found on the surface of plots treated with 0.01% bait. A total of five dead ground squirrels were found on the plots treated with the 0.10% bait. Carcasses of three other rodent and lagomorph species were found on the treated plots. Necropsies confirmed test substance exposure in some but not all non-target species found. No secondary poisoning cases were observed, although a coyote scat containing bait was found.

Whole carcass tissues of 12 ground squirrels retrieved from 0.01% baited plots and eight ground squirrels retrieved from the 0.10% baited plots were analyzed for bromethalin residues. Non-target carcasses were retrieved and examined for evidence of bait ingestion but were not analyzed.

Analysis of whole carcass tissue residues in recovered squirrels found mean residue loads of 1.01 mg (3.18 ppm) of bromethalin in squirrels exposed to the 0.01% a.i. bait and 4.35 mg (11.2 ppm) of bromethalin in squirrels exposed to the 0.10% a.i. bait.

Both baits were analyzed for concentration of the active ingredient immediately after mixing and again after field exposure. The nominal 0.01% bait assayed at 0.0088 to 0.0091% bromethalin initially. After 14 days exposure in bait stations, three samples assayed at 0.0087% bromethalin, representing a 4.4% decline. The nominal 0.10% bait assayed at 0.0875 to 0.0914% bromethalin initially. After 14 days exposure in a bait stations, three samples assayed at 0.0797% bromethalin, a decline of 8.9%.

Bromethalin shows promise as a field rodenticide due to the comparatively low amount of bait needed, and reduced secondary hazards.

ANTICOAGULANT RESIDUES ON ALFALFA

Ground squirrels (*Spermophilus* spp.) and voles (*Microtus* spp.) can be serious pests of alfalfa (*Medicago sativa*) at times. Rodent Bait Chlorophacinone Treated Grain 0.01%, and Rodent Bait Diphacinone Treated Grain 0.01% are available in California under a 24C label for controlling rodent pests in non-crop areas. The California Department of Food and Agriculture wishes to obtain a label claim for use of this bait against voles and other rodents in alfalfa crops. However, potential residue loads in treated crops have not yet been examined.

Much of the alfalfa grown in California supports the dairy industry. These studies were designed to determine the residue loads that dairy cattle or other livestock might be exposed to at proposed application rates, and at rates exceeding the label directed rates.

The bait was applied at two sites representing different regions of California. The first site was in Modoc County in northeastern California, where three cuttings per season are typical. The second site was in San Joaquin County, near Stockton, where there may be six or more cuttings a year. Sites were selected based on the suitability for test applications and sampling, regardless of current rodent infestations.

Applications were made at different times in order to represent a variety of conditions under which the bait might be used. In Modoc County, the applications were made in early May, soon after the crop had broken dormancy and 42 days prior to cutting. The crop had begun to leaf out and, therefore, presented a greater opportunity for residue capture on the foliage. In San Joaquin County, the applications were made in early September, just after the fifth cutting of the year and 25 days prior to cutting.

The bait was applied by a truck mounted broadcast seeder. Two applications were made at two-day intervals at each site. A constant supply must be available for several days for the product to be effective against the target species. One plot at each site received a nominal application rate of 10 pounds bait/acre/application. A second plot at each site received a nominal application rate of 20 pounds bait/acre/application. A placebo bait containing all inert ingredients was applied to control plots at the same rates.

It has been estimated that crimped oat groats such as the type used here, uniformly broadcast at a rate of 10 pounds/acre will result in 4.1 kernels/square foot (Clark 1994). This is based on an estimated 18,000 kernels per pound of grain. Therefore, two applications at 10 pounds per acre would result in 8.2 kernels/square foot, and two applications at the 2X rate of 20 pounds/acre would only result in 16.4 kernels per square foot.

Chlorophacinone and diphacinone are only sparingly soluble in water (The Pesticide Manual 1991). Therefore, the primary means of plant exposure is through residue capture on foliage and stems during application. Samples of alfalfa representing three crop fractions—stems and new growth, mature foliage, and hay—were collected for analysis.

Alfalfa samples were collected prior to treatment, immediately after treatment, and about every two weeks until harvest. Cut hay samples were also collected.

Samples were analyzed for chlorophacinone and diphacinone residues by Genesis Laboratories, Inc. in Wellington, Colorado, using validated High Performance Liquid Chromatography (HPLC) methods.

The chlorophacinone method limit of detection for all crop fractions is $\leq$ 77.3 parts per billion (ppb). The limit of quantitation is defined as 10X the limit of detection. Possible residues were detected in only two samples from the Modoc County site plot treated twice at the 20 pounds/acre rate, 26 days post-treatment. These residues were near the limit of detection and well below the limit of quantitation. No residues were detected on any other samples in the study. No detectable residues were found on any of the other samples.

The diphacinone method limit of detection for all crop fractions is $\leq$ 76.4 ppb. No detectable residues were found on any of the samples.

The results are consistent with what might be expected considering: 1) the low rate of bait kernels per square foot applied; and 2) the relatively rapid degradation rate of these compounds when exposed to weathering, as established in the earlier field efficacy studies reported above. The use of these baits for rodent control in growing alfalfa should not present a hazard to livestock.

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THE DEVELOPMENT OF AN INTEGRATED PEST MANAGEMENT PLAN FOR ROOF RATS IN HAWAIIAN MACADAMIA ORCHARDS

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ABSTRACT: Roof rats (*Rattus rattus*) damage an estimated 5 to 10% of the developing nut crop in Hawaiian macadamia (*Macadamia integrifolia*) orchards. Relevant aspects of roof rat biology in macadamia orchards have and continue to be studied with the ultimate goal of developing an ecologically sound and cost-effective integrated pest management plan. The field component of a two-year study of roof rat populations in macadamia orchards has recently been completed. The goal of this study is to clarify the relationship between roof rat seasonal abundance, macadamia flowering, and nut production on five orchards in three regions on the island of Hawaii. The authors herein present preliminary results from selected aspects of this research. This and other completed studies on rat feeding locations and the effect of simulated rat damage during different stages of nut development will aid in the determination of critical points in the crop cycle when rats cause significant economic damage and control of damage is warranted. This paper is intended to be an overview of research leading to the development of a realistic integrated pest management plan for roof rats in Hawaiian macadamia orchards.

KEY WORDS: integrated pest management, *Macadamia integrifolia*, *Rattus rattus*

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INTRODUCTION

Hawaiian macadamia orchards (*Macadamia integrifolia*) provide roof rats (*Rattus rattus*) with abundant food and cover (Tobin 1992a, b). Mature macadamia kernels are composed of 71 to 75% oils and are a rich energy source (Tobin 1992a; O'Mara 1977). The cavities and crevices in the lava rock substrate of most Hawaiian macadamia orchards provide resident rats ample harborage (e.g., nests and burrows). Interlocking branches facilitate safe movement of rats among mature macadamia trees. If food supplies within a macadamia orchard are inadequate, windbreaks and adjacent noncrop wastelands provide alternative food.

Roof rats damage an estimated 5 to 10% of the Hawaiian macadamia crop (Fellows 1982; Tobin 1990). During the 1995 crop year, Hawaiian growers produced 52.5 million pounds net wet-in-shell macadamia nuts valued at $36 million (Hawaii Agricultural Statistics Service 1996, cited in Tobin et al. 1997a). This would mean that projected farm value losses due to rats in Hawaii in 1995 ranged between $1.8 to $3.6 million.

A long-term intensive research effort has been conducted by staff of the National Wildlife Research Center Hawaii Field Station to reduce the impact of rodent depredation in Hawaiian macadamia orchards (Fellows 1982; Fellows et al. 1978, 1988; Pank et al. 1978; Tobin 1990, 1992a,b,c,d, 1995a,b; Tobin et al. 1993, 1994, 1996a,b, 1997a,b). One goal of this research has been to supply macadamia farmers with an integrated pest management plan for roof rats that would reduce the impact of this pest species in a cost-effective, ecologically sound manner. Such plans have been designed in North America for red-winged blackbird (*Agelaius phoeniceus*) depredation on corn (Dolbeer 1990) and vole (*Microtus* spp.) depredation on fruit orchards (Tobin and Richmond 1993). In each of these publications, the authors clarified the relationship between vertebrate pest abundance levels and phases of a crop's life cycle with the intent of identifying the point that a pest causes significant economic damage. Present and past efforts by researchers studying roof rat depredations in macadamia orchards similarly are attempting to answer this question.

This publication has two distinct goals. The first is to review several research findings that will aid managers in understanding the relationship between roof rat biology and macadamia crop cycles and the implications of this information for better rat control in macadamia orchards. The second goal of this paper is the presentation of initial results of selected aspects of a two-year study of roof rat populations in macadamia orchards from three regions on the island of Hawaii.

A REVIEW OF PAST RESEARCH HIGHLIGHTS

Relative Importance of Macadamia Nuts in Roof Rat Diets in Macadamia Orchards

During an 11-month period between June 1990 and April 1991, roof rats were collected from a macadamia orchard near Hilo, Hawaii to determine relative dietary composition (Tobin 1995a; Tobin et al. 1994). All 199 rats (mean monthly number of rats collected = 18, SE = 1.9) collected for this study had macadamia nuts in their stomachs. Macadamia nuts were the major item in all stomachs examined. Fragments of macadamia nuts were present in stomach samples with an average relative abundance of 85% (SE = 2%, N = 11 months). Insect fragments were present in 66% of all rat stomachs and had an average relative abundance of 8% (SE = 2%, N = 11 months). Moss sporophytes, seta or capsules were present in 48% of all rat stomachs and had an average relative abundance of 4% (SE = 1%, N = 11 months). Non-moss vegetation, fruit seeds, and non-insect animal matter occurred in minor amounts (average relative abundance < 1%). The results of this study strongly support the observation that roof rats foraging within macadamia orchards use nuts as a primary food resource. Certainly, roof rat depredation could seriously impact macadamia nut yield and quality.

Effects of Roof Rat Trapping on Rat Populations, Nut Damage, and Yield of Macadamia Nuts

The effect of intensive snap trapping on roof rat populations in a macadamia orchard near Hilo, Hawaii was evaluated during the 1990-1991 and 1991-1992 crop cycles (Tobin 1992a; Tobin et al. 1993). Nut damage and macadamia yield were compared between sites where roof rat populations had and had not been controlled. As expected, roof rat abundance declined appreciably where snap trapping was undertaken. The control of roof rats in selected macadamia orchards reduced cumulative rat damage in trapped sites compared to reference sites during both crop seasons. Surprisingly, trapping had no effect on macadamia yields at harvest: the number of nuts, mass per unit and the total mass of undamaged nuts did not differ between the trapped and reference sites. These results suggest that researchers and managers should examine crop yield more closely when assessing the efficacy of roof rat control in macadamia orchards. Additionally, indices such as the proportion of nuts damaged by rats may exaggerate the ultimate effectiveness of rat control measures in Hawaiian macadamia orchards.

The Effect of Simulated Rat Damage on Yields of Macadamia Trees

The previous study prompted researchers into further investigation of the effect of rat damage on the yields of macadamia trees (Tobin et al. 1996a; Tobin et al. 1997a). During the 1995 crop season, a simulated rat damage study was conducted at two locations on the island of Hawaii. Ten to 30% of the developing nut clusters were removed from selected five-year-old trees at 90, 120, or 150 days post-anthesis (dpa). Mature nut yield for all macadamia trees used in this experiment was measured at harvest (210 to 215 dpa). Removal of 10% of developing nut clusters, regardless of timing, had no measurable effect on yield compared to a control group. Similar results were also observed for trees where 30% nut clusters were removed at 90 and 120 dpa. Significant differences were observed between treated trees and control trees when 30% of nut clusters were removed at 150 dpa. Overall, these results suggest that growers should focus efforts to manage rodent damage during later phases of nut development (>150 dpa). However, if rodent populations are extremely high and damage levels exceed 30% of nut clusters earlier in the crop cycle, macadamia trees may be less likely to compensate for this damage. In such situations, rodent control should be focused earlier in the crop cycle. The researchers are currently initiating a second experiment to investigate the impact of simulated rodent damage during the later phases of nut development (>150 dpa), when the impact of high levels of rodent damage may have greater impact on the yield of macadamia trees.

Movement Patterns and Seasonal Activity of Roof Rats in Hawaiian Macadamia Orchards

Radio transmitters were placed on 54 rats between November 1991 and May 1992 to determine movement patterns and seasonal activity in a macadamia orchard near Hilo, Hawaii (Tobin 1995a, b; Tobin et al. 1996b). The mean minimum convex polygon home ranges for all roof rats radio collared was 0.2 ha (SE = 0.02) with no significant difference (F = 1.93; 1, 48; P = 0.017) in home range detected between males (0.22 ha, SE = 0.02, N = 21) and females (0.18 ha, SE = 0.025, N = 33). Similarly, no significant differences were observed in rat home ranges for both sexes among the three seasons (peak harvest, peak anthesis, and midseason) of the macadamia crop cycle (F = 0.62; 2, 48 df, P = 0.54). It is interesting to note that no rats were located on the ground during this foraging study. All radio-collared rats were located either in trees or in burrows. This result led researchers to question the efficacy of the common practice of broadcast baiting of zinc phosphide coated oat groats in Hawaiian macadamia orchards and stimulated the following study.

Bait Placement and Acceptance by Rats in Macadamia Orchards

Using a non-toxic oat bait treated with a 0.75% tetracycline hydrochloride (THC) marker, researchers determined effectiveness of differing bait placement for roof rats in macadamia orchards (Tobin et al. 1997b). THC-marked baits were broadcast on the ground, placed in burrows on the ground, and put in branch crotches in trees in macadamia orchards located in three regions on the island of Hawaii (Keaau, Hamakua, and Kona). Due to substrate differences between study sites, THC-treated baits were placed only in rat burrows at two study sites (Keaau and Kona). Thirteen to 18 days following bait placement, rats were snap trapped in treated orchards to determine the proportion of marked rats associated with differing baiting regimes. Orchards where THC-treated bait was placed in trees had the greatest percentage of marked animals (Keaau 91%, Hamakua 79%, and Kona 70%), while orchards where THC-treated bait was broadcast on the ground had the lowest efficacy (Keaau 36%, Hamakua 11%, and Kona 0%). Placement of bait in rat burrows had an intermediate level of effect (Keaau 70% and Kona 57%). These results suggested that the placement of toxic bait in trees is the most effective way to control roof rats in the macadamia orchards. Additionally, these results show that the broadcast baiting of rodenticides on the ground in macadamia orchards without interior ground vegetation is ineffective.

A TWO-YEAR COMPARISON OF RODENT ABUNDANCE IN MACADAMIA ORCHARDS ON THE ISLAND OF HAWAII: PRELIMINARY RESULTS FROM THREE SITES

The researchers recently completed the field component of a two-year study of rodent populations in macadamia orchards on the island of Hawaii. The ultimate goal of this study is to clarify the relationships among rodent seasonal abundance, macadamia flowering, and nut production in five orchards from three climatically different regions on the island of Hawaii (Figure 1). Previous observations indicated that rat abundance in orchards varies widely on the island of Hawaii both geographically and temporally. Climatic factors such average annual rainfall, which ranges between 250 mm to >11,000 mm on the island of Hawaii (Giambelluca and Sanderson 1993), and differing cultural practices may strongly influence rodent abundance in orchards.

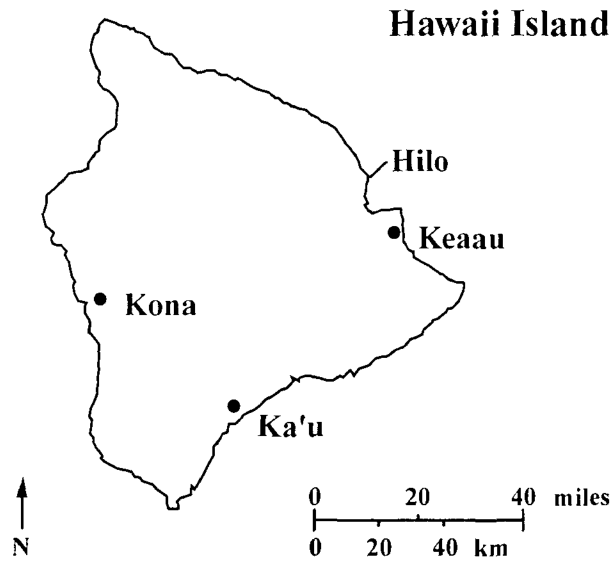

Figure 1. Map of the island of Hawaii showing sites where a two-year study of rodent populations in macadamia orchards was conducted.

In this publication the researchers present preliminary results comparing rodent abundance and rodent species composition for infield and noncrop areas for three orchards (Keaau-57, Kona-P, and Ka'u-61-01) that are representative of macadamia orchards from different regions of the island of Hawaii. During 1996 and 1997, rodent abundance was sampled in each orchard along standardized transects at intervals of approximately two months (i.e., N = 12 for two years, one sample per 60 day period). In each orchard, 100 standard rat traps with enlarged (5 X 5 cm) triggers were placed in orchard and noncrop habitat (50 rat traps per habitat, respectively). In orchards, rat traps were placed on the lower lateral branches of trees (approximately 0.75 to 2.75 m above ground). In noncrop habitat rat traps were placed on the ground. All rat traps were pre-baited and baited with coconut chunks. Each trapping session in a particular orchard lasted four nights with two nights of pre-baiting and two nights of trapping. All captures were labeled in the field and taken to the National Wildlife Research Center Hawaii Field Station for identification and necropsy.

To assess changes in rodent abundance among sites, a relative index of trap success that adjusted for tripped traps ("corrected capture success") was calculated for each night of trapping (Nelson and Clark 1973; Innes 1990). No significant seasonal trends in rodent abundance were observed for either infield or noncrop sites in the three orchards sampled during the two years of this study (Figure 2). One-tailed paired t-tests were used to detect significant differences in rodent abundance within each orchard between noncrop and infield sites during the study. No significant differences were detected in rodent abundance over the two year study between the infield and noncrop sites in the Ka'u-61-01 orchard ($t = 0.24$, 11 df, $P = 0.23$). Significant differences in rodent abundance were detected between infield and noncrop sites in the Keaau-57 and Kona-P (respectively, $t = -6.77$, 11 df, $P = 0.000002$; $t = 3.24$, 11 df, $P = 0.004$). Kona-P had significantly greater rodent captures in infield sites compared to noncrop, a trend opposite of that observed in Keaau-57.

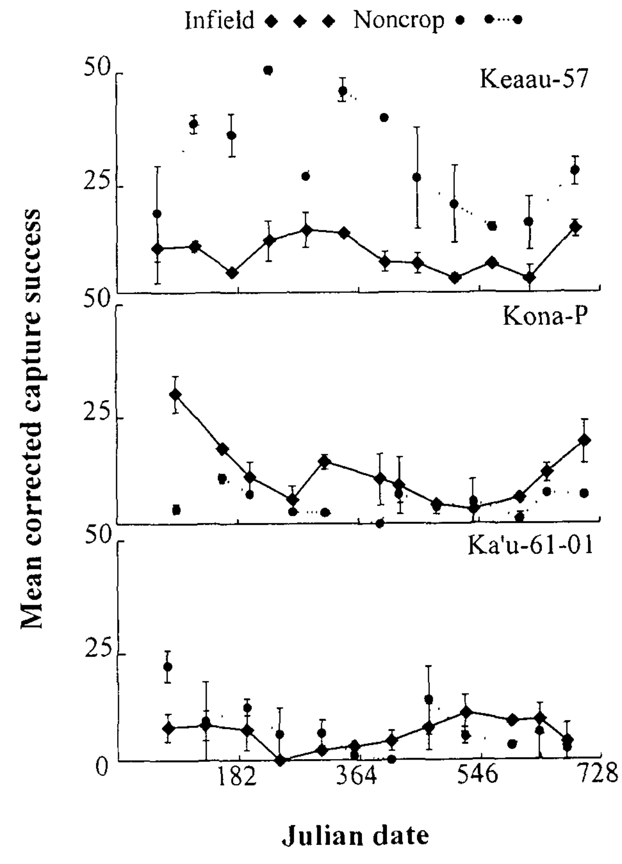

Figure 2. Mean corrected rodent capture success and standard error (N = 2) for four species of rodents combined (roof rat, Polynesian rat, Norway rat, and field mouse) from infield and noncrop habitats in three macadamia nut orchards on the island of Hawaii during a two year period. Traps were set and monitored for two nights at approximately 60-day intervals at each site.

The most frequently captured identifiable rodent species in infield sites in the three macadamia orchards were roof rats (100% Kona-P, 98% Ka'u-61-01, and 93% Keaau-57) (Figure 3). Roof rats comprised a greater proportion of the rodent community in all infield sites compared to adjacent noncrop sites. Seven percent of the rodents captured in infield habitat at Keaau were Polynesian rats (*Rattus exulans*); Norway rats (*Rattus norvegicus*) comprised 2% of the rodent captures in K'au-61-01. House mice (*Mus musculus*) were never captured in infield habitat in the three macadamia orchards sampled. In non-crop sites, the most common species of rodent captured was roof rat (mean = 44%, SE = 6%, N = 3 sites) followed by house mouse (mean = 35%, SE = 12%, N = 3), Polynesian rat (mean = 21%, SE = 14%, N = 3), and Norway rat (mean = 1%, SE = 0.3%, N = 3).

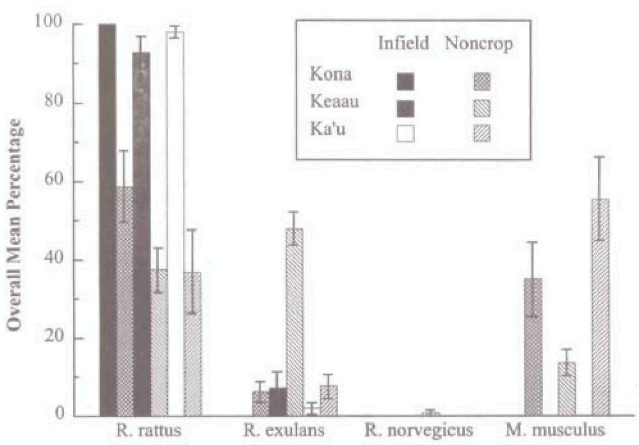

Figure 3. Mean percentage rodent species composition and standard error for four species of rodents (roof rat, Polynesian rat, Norway rat, and field mouse) captured in infield and noncrop sites in three macadamia nut orchards (Keeau-57, K'au-61-01, and Kona-P) on the island of Hawaii during a two-year period between 1996 and 1997 (N = 12). Traps were set and monitored for two nights at approximately 60-day intervals at each site.

Overall, these results confirm that roof rats are the primary rodent species foraging in macadamia trees in Hawaiian orchards. In adjacent noncrop habitats a suite of rodent species are found; primarily roof rats, house mice, and Polynesian rats. It should be noted that differing sampling techniques (e.g., tree vs. ground trapping) probably influenced the relative capture success of all rodent species in orchard (e.g., infield) vs. noncrop habitats. Roof rats are more arboreal than the other rodent species captured in this study, and thus more likely to encounter traps set in trees. Since previous studies have shown that roof rats forage primarily in macadamia trees in Hawaiian orchards this sampling technique was most efficient for this species. Placement of rat traps on the ground allowed standardized comparisons among different noncrop habitats due to habitat variability (e.g., grassland, secondary forest, scrub) between noncrop sites.

No significant seasonal trends were observed in rodent abundance for either noncrop or infield habitats sampled. Trends in rodent abundance and species composition could be attributed to differing cultural practices and local climate. In the case of Keaau-57, significantly higher rodent abundance levels in noncrop areas compared to infield areas could be due to removal of all debris from the orchard floor, a common practice in many large commercial orchards that reduces harborage and alternative foods for rodents. Noncrop areas near Keaau-57 were mixed secondary forest with undergrowth, which provide food and harborage for all species of rodents sampled in this study.

Kona-P is a small orchard surrounded by dry scrub and grass. Rodent abundance was significantly higher for infield habitat in Kona-P compared to noncrop habitat. In this orchard rocks which were piled up around the base of each macadamia tree to provide support potentially provided additional harborage for rodents living in the orchard.

No significant difference in rodent abundance was observed between infield and noncrop sites for the Ka'u-61-01 orchard which was located on a large commercial orchard in a dry area of the island. Like the Keeau-57 orchard, K'au-61-01 had little debris on the forest floor. Unlike Keeau-58, K'au-61-01 was bordered by grassland and dry scrub. These two factors probably reduced the suitability of both infield or noncrop habitats near K'au-61-01 for rodents.

SUMMARY

To design an effective integrated pest management plan for roof rats in Hawaiian macadamia orchards, the relationship of roof rat abundance and the crop's life cycle needs to be understood. Past and present research by staff of the National Wildlife Research Center Hawaii Field Station have been directed toward this goal. Past research efforts have identified several key points leading to a successful integrated pest management plan for roof rats in macadamia orchards. First, roof rats are the primary rodent pest species of concern for macadamia producers. Second, broadcast baiting of rodenticides on the ground in macadamia orchards without interior vegetation is ineffective for roof rat control. Third, macadamia trees can compensate for rodent damage early in the crop cycle. Presently, Hawaii Field Station staff are examining the potential for registration (United States Environmental Protection Agency 24c registration) of anticoagulant rodenticide use in bait boxes in macadamia trees. If such registrations are developed, they could provide macadamia producers with a precise technique to control roof rat damage at the sites where it occurs.

Continuation of damage simulation studies will help farmers determine economically significant thresholds for employing measures to control rat depredation in Hawaiian macadamia orchards. This two-year study of the relationship between roof rat seasonal abundance, macadamia flowering, and nut production in three regions on the island of Hawaii will allow farmers to tailor their rodent control plans to their specific situations. Each of these steps, supported by data from past research, will facilitate the development of an integrated pest management plan for roof rats in Hawaiian macadamia orchards.

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THE BAIT SURCHARGE PROGRAM: RESEARCH IMPROVES ZINC PHOSPHIDE USE FOR VOLE CONTROL IN ALFALFA

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ABSTRACT: This paper describes several unexpected benefits of rodenticide-registration research funded by The California Bait Surcharge Program. An enclosure-type study was conducted to determine efficacy of single, pre- and test-bait broadcasts (10 lb./ac.) of 0% and 2% zinc phosphide (Zn_3P_2, CAS #1314-84-7) steam-rolled-oat (SRO) groats to control voles (*Microtus* spp.) in alfalfa (*Medicago sativa*). Unexpected research spinoffs resulted from the use of: 1) eight randomly-located, sieved-dirt plots per enclosure to monitor bait distribution, bait removal, and rodent/avian (non-target) activity; 2) a bait-weathering plot and bait-sample analyses to monitor Zn_3P_2 biodeterioration; and 3) a C^{++}-language program to derive theoretical benefit-cost ratios associated with Zn_3P_2-bait broadcasts.

KEY WORDS: rodenticide, zinc phosphide, field rodents, voles, *Microtus* spp., alfalfa, *Medicago sativa*, benefit-cost, pesticide registration

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INTRODUCTION

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA-88) was amended for the fourth time in 1988 (Federal Insecticide, Fungicide, and Rodenticide Act 1988). Shortly afterwards, the Environmental Protection Agency (EPA) implemented Good Laboratory Practice (GLP) and Quality Assurance (QA) standards (EPA 1989). Together, these events increased the costs associated with registrations of pesticides and decreased the number of registrations/reregistrations maintained or initiated in the U.S. (Sterner and Fagerstone 1997).

By 1990, the California agriculture industry realized the impact of FIFRA-88, GLP, and QA regulations on pesticide registrations; growers/ranchers urged (successfully) the California legislature to pass a bill that required each county agricultural commissioner to collect \$0.50/lb. for pest control materials sold, distributed, or used within the state (Vertebrate Pest Control Research Advisory Committee 1994). This "surcharge" provided funds for the registration/reregistration of pesticides. Registration and related research activities would be decided by a Vertebrate Pest Control Research Advisory Committee (VPCRAC), with actual funds/studies monitored by the California Department of Food and Agriculture (CDFA).

In 1992, CDFA initiated a cooperative agreement with the U.S. Department of Agriculture's former Denver Wildlife Research Center (now National Wildlife Research Center). Efficacy and non-target avian hazards studies were needed to register broadcast applications of 2% zinc phosphide (Zn_3P_2) steam-rolled-oat (SRO) groats for vole control (*M. californicus*, *M. montanus*) in alfalfa. Sterner et al. (1994, 1996) reported the results of this efficacy study; whereas, Ramey et al. (1994) and Ramey and Sterner (1995) reported findings of a concurrent study that monitored non-target avian hazards posed by the baits to ring-necked pheasants (*Phaisianus colchicus*) and California quail (*Callipepla californica*). It was shown that successive 10 lb./ac. broadcasts of placebo and lecithin-adhered Zn_3P_2 SRO groats in alfalfa were associated with >94% reduction of introduced voles (Sterner et al. 1994, 1996). Procedures included: 1) an initial 10-day trapout of rodents from 18, 0.5 ac. enclosures; 2) the distribution and acclimation of 428 gray-tailed voles to enclosures (*M. canicaudus*; 23 or 24 voles/0.2 ha enclosure [~125/ha], with genders typically balanced); 3) the distribution of 52 ring-necked pheasants (7 roosters and 45 hens) and 51 California quail (7 roosters and 44 hens) into enclosures; 4) a pre-bait (placebo) broadcast and two-day exposure period; 5) the broadcast of placebo or test baits in nine randomly selected enclosures (3 each designated vole-only, vole-pheasant, and vole-quail, with 8 or 9 birds [≥1 rooster] assigned to respective vole-pheasant and vole-quail enclosures), with a subsequent 14-day exposure period that involved a daily search for vole and non-target carcasses; and 6) a subsequent ≥10-day enumeration (trapout) of the remaining voles.

This paper identifies several research spinoffs that were realized by Sterner et al. (1994, 1996). Methods devised to assess pre-bait effectiveness, bait distribution/pick up, bait biodeterioration, and vole/pheasant/quail activity after Zn_3P_2-bait broadcast have utility to other studies; a theoretical benefit-cost analysis affords insight into the economics of Zn_3P_2 broadcasts for vole control.

RESEARCH BENEFITS

Product Performance Guideline (GDLN) 96-12 (EPA 1982) and CFR 40 (EPA 1996) provide suggested methods/endpoints and GLP procedures needed to satisfy the registration requirements for efficacy determinations of rodenticides. Nevertheless, study directors have latitude to devise/implement novel data collection procedures that will aid evaluations of effects in these studies.

The methods outlined in GDLN 96-12(e) for field efficacy studies and development of a Section 3 (federal) label state that registrants/researchers should: i) submit ≥5 studies for each formulation, site, method of application, major region and species claimed to be controlled by the rodenticide; ii) perform pre- and post-treatment population censuses of rodents (i.e., either direct [capture, mark, release, recapture] and/or indirect [opened or closed mounds/burrows]); iii) use separate control ("placebo") sites; iv) include trials involving different rates, frequencies, and modes of application for baits; and v) conduct studies with environmental factors (e.g., humidity, rainfall, temperature) similar to those expected for future use conditions (EPA 1982). Sterner et al. (1994, 1996) used direct censusing of gray-tailed voles within enclosures under fairly arid conditions (similar to those expected for autumn broadcasts in the Imperial Valley of California), with separate enclosures as control sites. Because VPCRAC envisioned data for a 24c ("special local need") registration to broadcast Zn_3P_2 SRO groats in alfalfa, certain of the aforementioned requirements did not apply (e.g., diverse regional studies, open/closed burrows).

Pre-bait Acceptance Plots and Bait-broadcast Criterion

A key issue facing pesticide applicators and researchers attempting to broadcast Zn_3P_2 concerns the economics/utility of pre-baiting. Although Zn_3P_2 is an effective acute rodenticide for diverse rodents/applications, bait shyness in sub-lethally-dosed animals has been cited as a negative attribute (Gratz 1973; Marsh 1988; Sterner 1994; Tietjen 1976). Pre-baiting with a placebo bait is commonly believed to mitigate bait shyness. Allegedly, the use of a placebo (pre-bait) affords improved acceptance of a novel grain bait (reduced neophobia) and faster bait ingestion—reduction of sub-lethal toxicosis from Zn_3P_2 hydrolysis and phosphine (PH_3) generation when bait particles are eaten slowly by rodents (Murphy 1986; Sterner 1994).

Sterner et al. (1994, 1996) broadcast a lecithin-coated SRO groat (10 lbs./ac.) as pre-bait. Prior to the broadcast, eight 1 ft^2 sieved-dirt plots were prepared at random locations within each of the 18, 0.5 ac. alfalfa enclosures (Sterner et al. in preparation). Immediately following the pre-bait broadcast, personnel removed all SRO groats that had been broadcast onto these plots, and placed four placebo SRO groats on each plot—1 bait/0.5-ft^2 quadrant (32/enclosure). These plots were then monitored daily for placebo baits (removals) and vole sign. The absence of ≥ 1 ($\geq 25\%$) particle from ≥ 6 ($\geq 75\%$) plots within ≥ 9 ($\geq 50\%$) enclosures was the criterion used to determine sufficiency of placebo acceptance.

The "pre-bait" criterion was exceeded after two days of exposure; 6 and 13 enclosures had ≥ 1 ($\geq 25\%$) particle(s) removed from ≥ 6 ($\geq 75\%$) plots on Days 1 and 2, respectively (Sterner and Ramey in preparation). Although this criterion may be altered, this approach affords an empirical basis for timing the rodenticide broadcast; it also probably contributed to the 94.6% efficacy achieved.

Bait-distribution, Bait-removal, and Vole-/Non-target-avian Activity

The use of sieved-dirt plots within enclosures also helped delineate bait-distribution (density), bait-removal, and vole-/non-target-avian activity subsequent to pre-bait and test-bait broadcasts (Sterner et al. in preparation).

Bait-distribution. Broadcast of 2.5 to 5 crimped oats particles per 1 $ft.^2$ is considered typical for a 10 lb./acre application (T. Salmon, pers. comm. 1993). By immediately counting and removing bait particles from the eight random plots per enclosure, indices of broadcast calibration were obtained. The average ($\pm$SD) SRO groats distributed on plots during pre-bait and test-bait broadcasts (10 lb./ac.) ranged from 2.1 ($\pm$ 2.2) to 5.1 ($\pm$5.5) and from 1.1 ($\pm$1.4) to 6.9 ($\pm$9.1) per enclosure, respectively—confirmation of the adequate calibration of the Spyker® spreaders and applicators.

Bait-removal. In addition to the pre-bait data, cumulative daily counts of Zn_3P_2- and control-SRO groats missing from plots (n = 4/plot and 32/enclosure) served as a useful index of efficacy. All 32 particles were removed from the plots in the control-bait enclosures within 7 to 10 days after broadcast; whereas, 32 particles were removed from only 1 Zn_3P_2-baited enclosure during the 14-day bait-exposure period. These data concur with expected rodenticide effects; reduced vole populations in the Zn_3P_2-bait enclosures offer indirect support for efficacy—low numbers of voles precluded complete bait pick up of these baits.

Vole-/non-target-avian activity. The sieved-dirt plots were scored for the presence:absence (1:0) of vole and avian signs during early morning ($\sim$0800-0900 h). Footprint and tail drag sign of voles were distinctive (see Figure 1). Pheasant/quail sign were based largely upon footprints, feathers, droppings, dirt rolls, and soil scratches. Still, discrimination of pheasant and quail sign proved difficult, with footprint size or feather coloration the most reliable features for distinguishing the activity of the species.

Vole activity during the two-day pre-bait period averaged ($\pm$SD) 4.7-4.9 ($\pm$1.8-2.2) plots/enclosure (Sterner et al. in preparation). During the test-bait exposures, vole activity generally declined, but plots in Zn_3P_2-baited enclosures showed more dramatic reductions in activity than placebo-baited enclosures. Mean activity in Zn_3P_2-baited enclosures was 3.1 ($\pm$1.9), 1.2 ($\pm$1.3), and 0.67 ($\pm$0.86) plots for Days 1, 7, and 14 post broadcast, respectively. This compared to vole-activity means ($\pm$SD) of 4.7 ($\pm$1.5), 3.5 ($\pm$2.0), and 2.67 ($\pm$1.9) on Days 1, 7, and 14, respectively, for placebo-baited enclosures. The general decline is somewhat an artifact of precipitation which occurred late in the 14-day exposure period (i.e., 1.01 in. during the last several days) and somewhat obscured dirt plot readings. Nevertheless, the activity patterns again confirmed the efficacy data—lowered activity in Zn_3P_2-baited versus placebo-baited enclosures.

Avian sign on plots in the vole-pheasant and vole-quail enclosures confirmed the locations of the birds. A total of four incidences of avian activity on plots in "vole-only" enclosures were recorded and gallinaceous birds were found to have moved between enclosures on these occasions (Ramey and Sterner 1995).

Regarding activity within each of the six enclosures with pheasants or quail, mean ($\pm$SD) plots with sign during the pre-bait period were 5.4 ($\pm$1.5) and 1.6 ($\pm$1.4), respectively. This disparity between pheasant and quail use of dirt plots appeared valid. The pheasants were observed individually or in groups of two to three birds using the plots as dust rolls and foraging extensively wherever foliage was absent; the quail were observed to

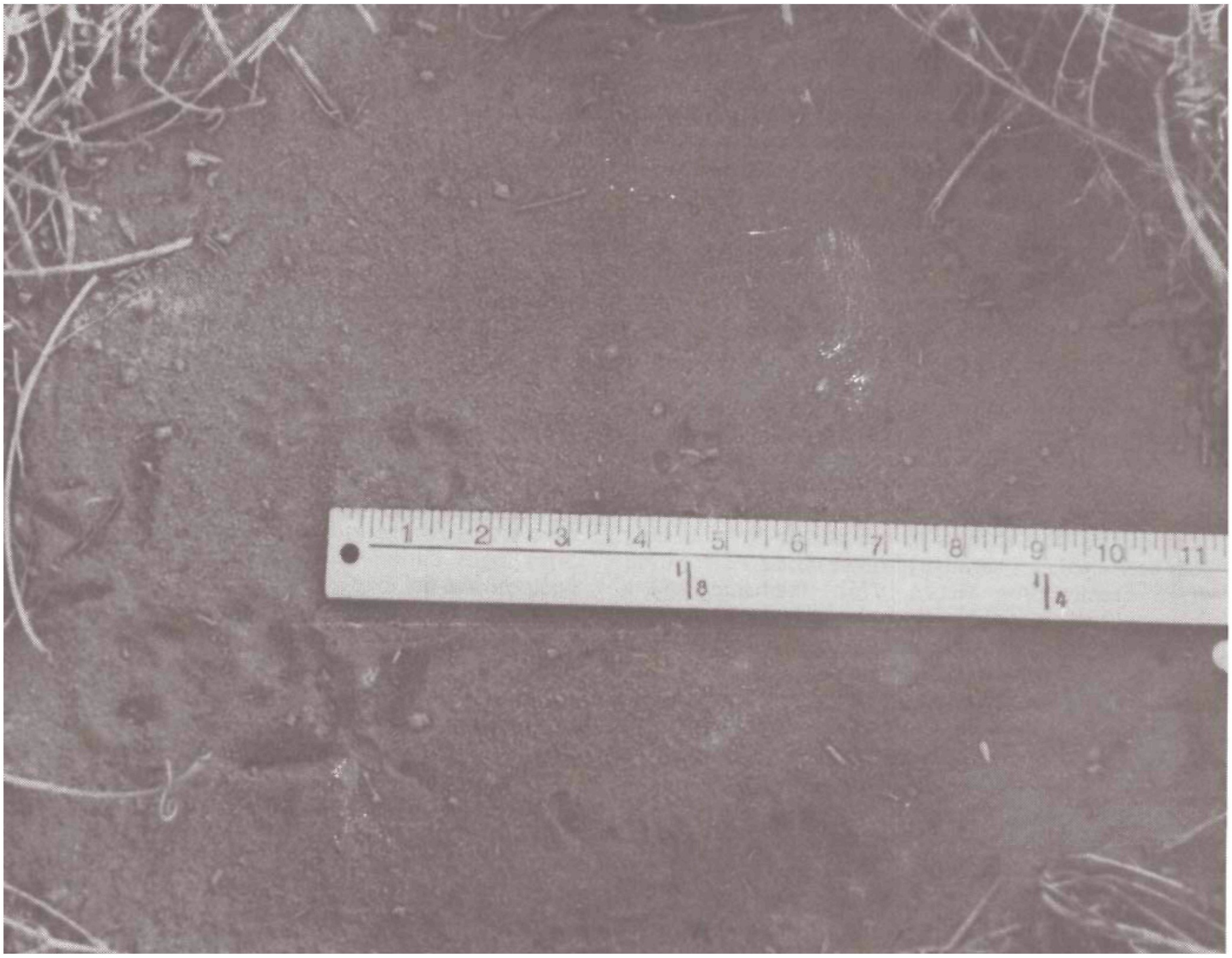

Figure 1. Photograph of a sieved-dirt plot that shows vole (footprints and tail drags) and avian signs (i.e., probable footprints of a ring-necked pheasant).

move as a covey along enclosure edges and less frequently dispersed throughout the foliage. Mean ($\pm$SD) avian activity within pheasant enclosures was 4.8 ($\pm$1.4), 4.0 ($\pm$3.2), and 3.3 ($\pm$2.7) for Days 1, 7, and 14 post broadcast, respectively; whereas, mean ($\pm$SD) avian activity in quail enclosures was 2.0 ($\pm$1.5), 2.3 ($\pm$1.4), and 2.5 ($\pm$1.4) on these respective days. Serendipidously, on two days, canid (probable coyote, *Canis latrans*) sign was also recorded within plots of avian enclosures.

Bait-biodeterioration Plot and Sample Analyses

Regarding the biodeterioration of Zn_3P_2, CFR 40 (Part 160.105) specifies that:

> (a) The identity, strength, purity, and composition, or other characteristics which will appropriately define the test, control, or reference substance shall be determined for each batch and shall be documented before its use in a study . . . (EPA 1996)

Although the time of this determination is not explicit and is based upon a number of considerations (e.g., stability, storage conditions), at the very least a pre-study analysis of the test material must be performed to demonstrate the a.i. present in a product at or near the time of use.

Sterner and Ramey (1995) published data showing the biodegradation of Zn_3P_2-SRO groats in alfalfa. Briefly, 2% Zn_3P_2 SRO groats were broadcast using Spyker® Model-75 Spreaders (Spyker Co., N. Manchester, Indiana). Approximately 2 lb. of this bait was also spread onto a 36 ft^2, 0.25 in. wire-mesh-covered plot. Samples of bait were then collected immediately after passage through the spreader, as well as on 1, 7, and 14 days after exposure to soil/weather conditions at the test site. Bait samples were stored in plastic bags and later analyzed for Zn_3P_2.

Results showed the temporal course of rodenticide biodegradation. Interestingly, of the 2.0% Zn_3P_2 comprising the test bait, 0.2% was "knocked off" of the

SRO groats due to the mechanical action of the spreader—1.8% Zn_3P_2 was actually present on broadcast bait; that is, ~10% of the available Zn_3P_2 was dislodged from the groats during broadcast. Analyses of Day 1, 7, and 14 samples also showed that ~30% loss had occurred between Days 1 and 7, with ~87% loss of a.i. noted by Day 14. No precipitation occurred during Days 1 to 7, but 1.01 in. of rainfall during Days 7 to 14—baits were essentially neutralized by Day 14. Although the reasons for the Day 1 to 7 loss is unknown, it could be attributable to a combination of: 1) soil pH (i.e., slightly acidic, 6.0 pH); and 2) dew (i.e., occurred nightly during the study and could have dripped from plants onto baits). Use of "bait-weathering" plots are recommended as standard practice in such product-performance studies.

Benefit:Cost Analysis of Zn_3P_2 Broadcasts

Sterner et al. (in review) developed a computer program to examine the economics of broadcasting 2% Zn_3P_2 SRO groat baits to control voles in alfalfa. Ratios were computed relative to the 1996 U.S. average alfalfa yield of 3.27 tons/ac. and price of $94.12/ton (USDA 1997). The benefit:cost ratio was computed as:

$$\text{Benefit:Cost Ratio} = \text{Savings (US \$)} \div \text{Costs (US \$)}.$$

Iterative runs of the program estimated costs/savings for all combinations of varied percentages of crop loss (5, 10, 15, 20, 25, 30%), rodenticide efficacy (75, 80, 85, 90, 95%), and application fee ($1, 2, 3, 4, 5, 6, 7, 8, 9, 10/ac.). The program assumed that outlays had to be recovered in a single cutting.

Benefit:cost ratios ranged between 0.44 and 4.78; these occurred for the projections of 5% loss x 70% efficacy x $10.00/ac. fee and 25% loss x 95% efficacy x $1.00/ac. fee, respectively. In general, ratios ≥2.0 occurred when crop loss was ≥15% and efficacy was ≥85%, irrespective of application fees. As expected, least expensive bait applications involve aerial and all-terrain-vehicle (ATV) broadcasts.

CONCLUSIONS

"Spinoff" from Bait Surcharge Program funded research to register Zn_3P_2 for broadcast in alfalfa has afforded diverse methodological and economical benefits. These include: 1) use of sieved-dirt plots and pre-bait particle removals can aid timing of Zn_3P_2-bait broadcasts and Zn_3P_2 efficacy; 2) use of these same plots can provide indices of bait distribution, bait removals, and target/non-target avian activity to confirm/disconfirm the effectiveness of Zn_3P_2-bait broadcasts; 3) use of a bait-weathering plot and periodic Zn_3P_2-bait analyses can document the time course of Zn_3P_2-bait biodeterioration; and 4) theoretical economic projections suggest that costs of aerial and ATV bait broadcasts can be recovered in a single cutting if vole damage exceeds 15% and vole control exceeds 85%.

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A SURVEY OF RABBIT DAMAGE AND CONTROL MEASURES USED IN THE EAST AND NORTHEAST OF SCOTLAND

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ABSTRACT: A postal survey conducted of 172 farms in the intensive farming areas of East and Northeast Scotland revealed that one in four farms considered that there was a serious rabbit (*Oryctolagus cuniculus L.*) problem. Although a wide range of crops was subject to damage, winter cereals and winter oilseed rape were particularly affected by grazing, especially in the winter and spring periods. Two-thirds of farmers reported damage to temporary and permanent grass in the spring. The most common methods used to control rabbit damage were day-time and night-time shooting. Most methods of control were considered to be cost and time effective.

KEY WORDS: rabbit, damage, control, survey, Scotland

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INTRODUCTION

Although the rabbit (*Oryctolagus cuniculus L.*) was believed to have been introduced into Britain in the 12th century AD. by the Normans, it was not until the breakdown of the feudal system that rabbits began to spread over much of the country. Changes in agricultural practice, such as the creation of hedgerows made ideal burrowing areas for rabbits to establish new, uncontrolled warrens. The control of game predators and the deliberate spread of rabbits for sporting purposes led to an increase in numbers and played an important role in their spread (Thomson and Worden 1956). For example, Shaw (1989) reporting from the diaries of a prominent Scottish landowner of the 19th century, noted that rabbits were not recorded in the north of Scotland until the early 1800s and how young rabbits were imported and very soon established a viable colony. The whole North was "swarming with the little pets" before the end of the century, which was considered by the diarist to be "such a benefit on the Highlands." However, a continuously increasing population of rabbits also meant an increase in the grazing damage caused to arable crops and grassland.

Various estimates have been made of the cost of rabbit damage to British agriculture, ranging from £50 million sterling in the 1950s before the arrival of the disease myxomatosis (Thomson and Worden 1956) to £80 to 120 million sterling in the mid-1980s (Anon. 1986). Most recently, a survey carried out by the Scottish Office Agriculture and Fisheries Department (SOAFD) in 1991 established that rabbit damage in Scotland was costing the agriculture industry in excess of £11 million sterling annually and that serious rabbit infestations occurred on over 25% of farms in the eastern and northeastern areas of the country (Kolb 1991).

To provide an up-to-date picture of rabbits, the damage caused, and control methods used, a survey of arable and mixed farms on the eastern, crop-growing side of Scotland was carried out in 1996.

METHODS

A questionnaire was devised following the guidelines of MacDaniel Jr. and Gates (1993), using a series of scaled questions to determine farmer opinion in the following areas :

a) What was the extent of damage and which crops suffered most damage from rabbit grazing ?
b) What control methods were used ?

Supplementary questions were used to ascertain whether any of these methods were carried out as sporting activities and whether they were regarded as being effective. Farmers were not given a definition of the word "effective."

c) Did the rabbit problem originate on the farm or on neighboring land ?
d) Further questions asked about the future for rabbits and the provision of advice and education. Respondents were invited to add written comments to the questionnaire.

Farms in the arable and mixed cropping areas of East and Northeast Scotland were selected randomly and independently from the Yellow Pages and the questionnaire was sent to 362 farms in June 1996.

RESULTS

One hundred sixty-eight usable questionnaires were returned by the cut-off time in August, giving a return rate of 46%.

a) *The extent of the rabbit problem.* The overall perception of rabbits was that they were a significant problem throughout most of the year. Just over a quarter of farmers (26%) considered that they had a major problem on their farms, and 44% believed that they had a rabbit problem of medium importance. Crops particularly affected appeared to be the winter sown varieties of wheat, barley and oilseed rape, particularly during the winter and spring seasons. Approximately half of the farmers in the survey reported that cereal crops were at least partially affected by rabbit grazing in the spring. Winter oilseed rape was particularly affected during its establishment period in the autumn. Almost two-thirds of permanent and temporary grassland was reported to be affected also in spring.

b) *Methods used to control rabbits.* Even though exclusion (fencing) was only used on just over one-third of farms, it was the method which was perceived by most farmers (87%) to be an effective means of controlling rabbit damage (Figure 1).

The most common method of rabbit control was shooting, with 70% of farms undertaking shooting in the day time and 59% at night. Night-time shooting was regarded as being more effective than day-time shooting. Less than half of the respondents regarded day-time shooting as being effective, though approximately one-third regarded rabbit shooting as a sporting activity as well as a means of control.

Poisoning rabbits by gassing, using hydrogen cyanide powder or aluminum phosphide tablets was the second most common method of reducing populations, used on 59% of farms, with both types of materials being used to the same extent. Gassing by professional vermin controllers was carried out on 44% of the farms that used that method, whereas 61% of gas pellet operations were carried out by farm staff.

Snaring was used on 22% of farms but was seen as an effective way of controlling rabbits and almost half of the farms that used this technique employed professional trappers. Use of a spring trap was the least popular method and was not considered to be either cost or time effective.

Rabbits were consumed on less than 8% of the farms where they were shot or trapped, though 20% of farms that snared, ferreted, or used box traps reported that they sold rabbit carcasses to a game dealer.

Regular outbreaks of myxomatosis were reported on most farms, though opinion appeared to be divided about the effectiveness of the disease as a means of moderating rabbit populations; 61% of farmers considered that it no longer played an important role.

c) *Did the rabbit problem originate on the farm or on neighboring land?* Over 55% of all respondents had fields which shared common boundaries with either railway tracks or woodland. More than 79% of farmers with these common boundaries reported that the adjacent land areas provided a reservoir for uncontrolled rabbit populations.

d) *Other highlights of the survey.* In answer to supplementary questions, over 88% of respondents felt that the public should be made aware of the problems that rabbits can cause for agriculture, and the majority considered that rabbit numbers should be restricted either by elimination (33%) or populations kept at low levels (52%); nearly 15% felt that rabbits should be confined to nature reserves.

Most farmers (58%) seemed to rely upon word of mouth for information about rabbit control, whereas only 26% sought advice from professional vermin controllers; less than 10% sought advice from state and commercial advisory bodies.

Only a small number of farmers (less than 5%) were members of co-operative groups such as rabbit clearance societies, though almost half indicated that they may be prepared to attend courses on control, but in many cases only if there was "something new."

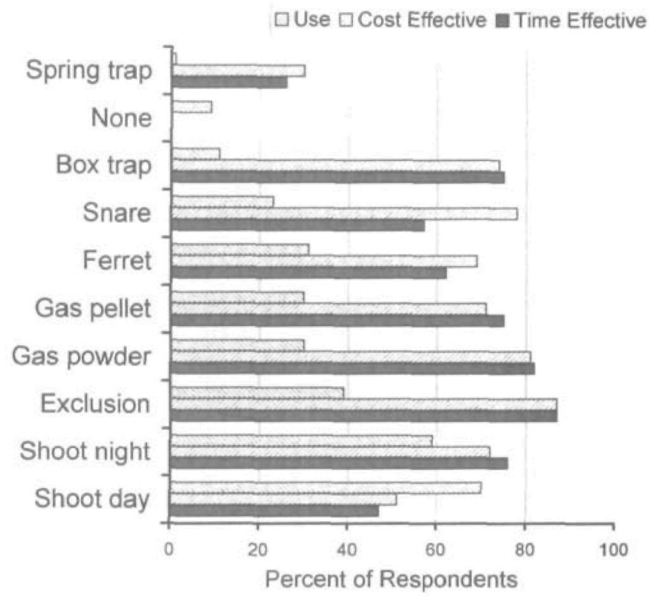

Figure 1. Responses to a survey of farmers in East and Northeast Scotland to determine methods used to control rabbits and the percentage of cost or time of each method.

Almost every respondent in the survey took the opportunity to add written comments to the returned questionnaire. Some highlights of these comments were:

- "It's such a large problem, it is beyond farmers to cope with it."
- "It could become the biggest problem in agriculture if not addressed now."
- The attitudes and role of the public towards wildlife is an important influence in the way in which rabbit populations could be controlled. References were made to "Watership Down" and Beatrix Potter, leading to "namby pamby" attitudes.
- Most farmers believed that a combination of control techniques was necessary.

DISCUSSION

The high rate of return for the questionnaire and the fact that most farmers elected to add extra written comments are clear indications that rabbits are regarded as a serious pest in Scotland. The reported proportion of farms experiencing a major rabbit problem (26%) confirmed the findings of Kolb (1994) that rabbits are considered by farmers to be an important problem on one in four Scottish mixed and arable farms.

Most control methods were perceived by farmers to be cost and time effective though they were not all commonly used. For example, almost nine out of ten farmers agreed that exclusion was effective, yet it appeared that this method was used on only four out of ten farms. Although day-time shooting was the most commonly used method of control, it was reported as the second least effective method after spring trapping, indicating that rabbits continue to be regarded as game animals as well as crop pests. Trout (1994) also reported that daytime shooting was the most common method for rabbit control used by over 70% of farmers, but one of the least effective. The techniques of gassing, which are well-recognized as being effective, were only implemented on one-third of farms, though this is a higher proportion than reported by Thomas (1995) in a government report on pesticide use in Scotland carried out in 1994.

Methods of control such as snaring, box trapping and ferreting, which produce clean, saleable carcasses, could be exploited as a way of contributing towards the costs of control operations (Fuchs et al. 1996). However, the reluctance of the British public to eat wild rabbit meat, since the arrival of myxomatosis (Sheail 1991) explains why the sale of carcasses does not appear to be important on most farms.

Comments on the returned questionnaires indicated that the reason only a third of farmers in the survey sought technical advice on rabbit control is perhaps due to the fact they feel that there is nothing new to learn about control methods at the moment.

Total eradication of rabbit populations was favored by a third of survey respondents, but this may not only be technically difficult, it would also probably be unacceptable to the general public even if there was a wider awareness of the destructive role that rabbits play in the countryside.

The survey highlighted that rabbit damage results not only from populations within the area of the farm, but also from neighboring agricultural and non-agricultural land where often no control measures are being used. Successful control will only come through the coordinated cooperation of farmers over a wide area, using a range of different methods.

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LABORATORY EFFICACY STUDY WITH A WARFARIN BAIT TO CONTROL THE BLACK-TAILED PRAIRIE DOG

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ABSTRACT: Control of the black-tailed prairie dog (*Cynomys ludovicianus*) is important for the reclamation of pasture ground for domestic cattle and limiting the spread of disease to humans and other wildlife. Six different concentrations of warfarin bait were fed to prairie dogs to determine mortality. Without the access to dietary vitamin K, the prairie dogs were susceptible to the warfarin bait. However, some of the prairie dogs recovered and survived the test after bait exposure was terminated. This could be due to physiological differences and the availability of fat-soluble vitamin K. The six different concentrations of warfarin consumed by the prairie dogs were correlated to the increase in treatment group (r=0.916). Body weight loss generally increased as the treatment group dosage increased. The control group was the only group which increased in body weight. The whole body tissue analysis of the prairie dogs from treatment groups 44.8, 233.0, and 777.6 ppm was correlated to the increase in treatment group (r=0.709).

KEY WORDS: *Cynomys ludovicianus*, black-tailed prairie dog, toxicant, rodenticide, warfarin, bioassay

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INTRODUCTION

Black-tailed prairie dog (*Cynomys ludovicianus*) numbers in the Great Plains were estimated at 5 billion in the early 1900s (Merriam 1902). At that period of history, they were considered to be a pest to the ranchers and farmers because of their feeding on crops and grass planted by the early settlers. Grazing biomass has been decreased by the feeding action of prairie dogs (Taylor and Loftfield 1924; Hansen and Gold 1977; O'Meilia et al. 1982; Knowles 1986). Prairie dogs are also a reservoir of disease that affect humans and other wildlife (Barnes 1982). For these reasons, the prairie dog is still being eradicated with the use of toxicants and firearms resulting in lower densities and widely scattered colonies (Clark et al. 1982; Foster and Hygnstrom 1990).

Even with the current small population of prairie dogs, the farmers and ranchers continue to use control techniques. The author is proposing warfarin as a possible answer because it is a cost effective rodenticide, it is relatively nontoxic to birds (Christopher et al. 1984; Hagan and Radomski 1953), it quickly degrades in the gastro-intestinal tract (half-life of 42 hours) (Ford 1993), it is rapidly excreted from the body (Wong and Solomonraj 1980), animals often do not develop "bait shyness" (Meister 1996), and it is relatively safe with respect to secondary poisonings (Aulerich et al. 1987).

The purpose of this study was to develop a concentration of warfarin bait from five formulations (0.005%, 0.01%, 0.025%, 0.05%, and 0.1%) that would be effective in the management of black-tailed prairie dogs.

OBJECTIVES

The objective of this bioassay test was to determine the efficacy of five concentrations of warfarin for managing black-tailed prairie dogs. Warfarin consumption was monitored to determine possible secondary hazard. Physical, behavioral, and anatomical observations were made to assess anticoagulant poisoning. Whole body tissue analysis was performed to calculate the warfarin accumulation at the time of death. Also, bait analysis will help determine if the mixing technique is sufficient to produce a homogeneous mixture.

In a companion study, the author tested the secondary hazard potential of warfarin-poisoned prairie dogs on domestic ferrets (*Mustela putorius furo*).

METHODS

Warfarin Formulations

Five concentrations of warfarin bait were tested (0.005%, 0.01%, 0.025%, 0.05%, and 0.1%). The warfarin technical product (99% purity) was supplied by Sigma Chemical. Three warfarin concentrates were made (0.5%, 1.0%, and 2.0% warfarin) for the five different warfarin formulations to aid in obtaining a sufficient homogeneity. Five warfarin formulations were prepared: 0.005%, 0.01%, 0.025%, 0.05%, and 0.1%. The control bait, which contained 0% warfarin, was mixed in the same manner as the other formulations. The exact formulation was kept in the raw data for confidentiality.

After each ingredient was added, the mixer was operated for 20 seconds to mix the ingredients together. When large amounts of the concentrate were to be added (500 and 1,000 ppm groups), small portions of the concentrate were added and then mixed for about 20 seconds. After all of the ingredients were added, the mixer was run for 15 minutes to achieve a homogenous mixture. Samples were collected from each formulation for freezer storage stability, animal room stability, and homogeneity. All of the formulated bait, including samples, were frozen in plastic bags. The bait was analyzed for freezer storage stability, animal room stability, and homogeneity.

Test System

All methods used in the study were approved by the Genesis Laboratories, Inc. Institutional Animal Care and Use Committee (Project #96018). Black-tailed prairie dogs were live trapped from a colony in Larimer County, Colorado. Traps were set near the burrow openings and worked into the ground to cover the metal bottom with soil. Clean rolled barley was placed on the trigger device as well as a path leading out of the trap for a distance of about 0.5 meters. Traps were checked at least twice daily.

The prairie dogs were transported to Genesis Laboratories, Inc. in the back of a covered truck in the same trap in which they were captured. All animals were dusted with flea powder containing pyrethrin to control ectoparasites.

The prairie dogs were placed into a cloth bag and plastic container, they were then weighed on a top loading Ohaus dial-o-gram balance. The scale had been calibrated and tared for the cloth bag and the plastic container. Maturity was assessed according to body weight (675 grams and 775 grams for females and males, respectively) (Hoogland 1995). Preliminary body weight was measured on the first day of the acclimation period when the prairie dogs were assigned to treatment groups. A final assessment of maturity by body weight was taken on Day 0 and were replaced with extra animals if they were underweight. Body weights were taken at test termination or death to assess weight loss or gain.

Prairie dogs were observed visually during the acclimation period. They were randomly assigned to cages from group housing one day before the acclimation period. The individual cages had metal screen bottoms with a surface area of at least 4,650 cm^2 and a minimum height of 46 cm (National Research Council 1992). Prairie dogs received a basal diet of laboratory pellets (Manna Pro Lab Cubes from St. Louis, MO), rolled barley, and water *ad libitum*. The bedding and water bottles were changed and cleaned weekly, and the water and feed levels checked daily. Cages and racks were not cleaned during the study because handling of the animals could cause lesions, bruises, or injury which could bias mortality estimates (Penumarthy and Oehme 1978).

The minimum/maximum temperature and humidity of the animal room was recorded daily during the entire holding period with a calibrated digital hygrometer/thermometer. The temperature and humidity in the study room was maintained at approximately 16 to 26°C and 55 ± 25%, respectively. Ventilation was checked often.

The animals were acclimated to test conditions for 10 days prior to the warfarin bait administration. Five females and three males were placed into acclimation with the initial group after the initial start date. One male was captured one day late, and two males and five females were captured two days late. These extra animals were used in the event some of the other animals did not reach the mandatory weight limits for each sex set by the study protocol.

Animals were randomly assigned to treatment groups, using the computer program "Ran30" (Faisal, Colorado State University, Fort Collins, CO), a program designed to choose random numbers according to the number that is required.

The feeding-test period was conducted for 15 days, during which all formulations were presented until the end of the test period or death. Seventy grams of each diet was presented daily in stainless steel feed cups. The feed cups were attached to a 30 cm X 30 cm sheet of particle board to catch spilled feed and stabilize the feed cup. A flat circular fowler with 10 mm holes, used for rodents, was placed over the bait to limit spillage. Bait consumption was measured and cups were refilled with fresh bait daily. After the exposure period, prairie dogs were fed the basal laboratory diet and observed for 10 days for signs of warfarin toxicity.

The prairie dogs were observed daily during their entire holding period. Any physical or behavioral signs that could help lead to the identification of sickness or anticoagulant poisoning during the test were recorded. The prairie dogs were observed once each day during the 10-day acclimation period. The prairie dogs were observed twice daily during the feeding-test period and post-test observation periods of the experiment. The Environmental Protection Agency (EPA) recommended the 15 day feeding and a 5 day post-test observation. A 10 day post-test was used to be certain of mortality. Necropsies were conducted on all animals that died during the test. An incision was made through the skin from the anus to the lower jaw. All major organs were observed for hemorrhaging and signs of anticoagulant poisoning in the abdominal and thoracic regions. A few cranial regions were incised to inspect for hemorrhaging.

After the prairie dogs were found dead during the test, the carcasses were labeled, wrapped in foil, and stored in a freezer for later analysis. Nine prairie dogs, three from each of the 50, 250, and 1,000 ppm treatment groups, were randomly chosen from the freezer to be analyzed for whole body residues of warfarin. This gave a representative range of the treatment groups. A laboratory-validated method was used. Also, all baits were analyzed for warfarin levels. A laboratory-validated method was used.

Statistics were performed after the completion of the test by SPSS for Windows, release 7.5. Various tests were performed based upon the capabilities and limitations of the available data. Linear regression was used to compare dependent and independent variables in relation to each other. Levene's test for homogeneity of variances was used to compare the variances within treatment groups. If the variances were significantly different, a Kruskall-Wallis non-parametric test was used to identify differences between variances. If the results of the Levene test showed the variances within the treatment groups were not significantly different, an analysis of variance (ANOVA), a parametric test, comparing treatment group means, was used to identify differences between the means of the variances.

Following analyses of variances, the Tukey's honestly significant difference test (HSD) was performed. This test identifies significant differences of the means of the treatment groups. The test shows which treatment groups are similar and which are different from the others. Significance values classify the significant difference between the treatment groups which are most distant from each other.

The computer program "Probit" (Charles Breidenstein, former section chief of statistics, Denver Wildlife Research Center) was used to calculate the LC_{50} and LC_{90} values.

RESULTS

The warfarin baits used in this study were formulated to be a nominal concentration of 50, 100, 250, 500, and

1,000 ppm. The validated analytical extraction procedure resulted in warfarin baits of actual concentrations of 44.8, 89.5, 233.0, 407.0, and 777.6 ppm. For the remainder of the report, the actual concentrations will be used for all calculations and presented results.

The daily observations taken during the exposure period included symptoms of diarrhea, ataxia, immobility, hemorrhage, hyperreactive, hyporeactive, bloody stool, labored breathing, hind limb paralysis, moribund, and found dead. During the first five days of the exposure period, only one female prairie dog showed a sign affiliated with warfarin intoxication—lethargy. On days 6 through 10, the prairie dogs began showing signs of hemorrhaging (nose, mouth, anus) or lethargy, with increasing severity as the study progressed. The first death was on day 8 of the exposure period. On days 11 to 15, the severity of the symptoms continued to progress with more individuals becoming moribund or found dead.

After the feeding test exposure, the animals were placed in a 10-day post-test observation period. Some of the animals continued to deteriorate physically, while some of the animals began to show improvements in their physical condition. In an extreme case, M23, in the 233.0 ppm treatment group, was classified as being "moribund" (M) for 13 days, and then upgraded to lethargic (HY) on day 8 of the post-test observation period.

Variances among the treatment groups differed significantly ($\underline{P}$=0.128). An ANOVA showed a difference between the treatment groups ($\underline{P}$<0.000). Tukey's HSD test identified a difference between the control group and the treated groups, and only a small difference among the treated groups (Tukey's HSD=0.430, $\underline{P}$<0.05) (Figure 1).

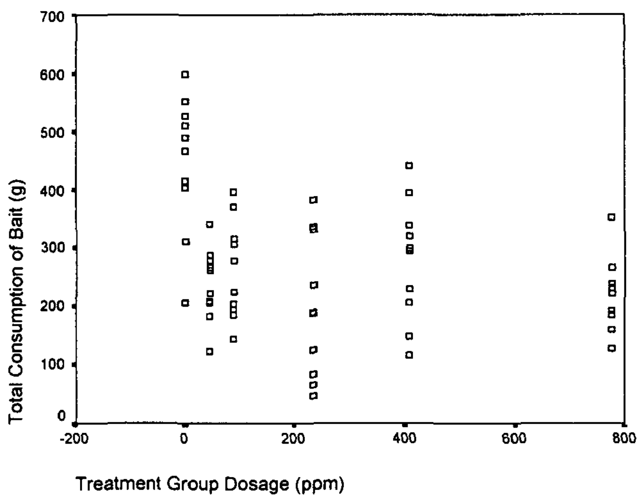

Figure 1. Total consumption of bait (grams) by prairie dogs fed six different concentrations of warfarin bait. The prairie dogs were fed for 15 consecutive days in a no-choice regime. Each square represents the consumption of one prairie dog.

Warfarin consumption was highly correlated (r=0.916) with the concentration of warfarin baits presented (Figure 2). A Levene test of homogeneity of variances showed that there is a difference between the variances among the treatment groups differed significantly (11.647, df_1=5, df_2=54, $\underline{P}$<0.000). A Kruskall-Wallis test indicated that the treatment means were different (P>0.000). Consumption of the two highest concentrations was significantly greater (Tukey's HSD=1.000, 10.00 at $\underline{P}$<0.05) than the three lower concentrations.

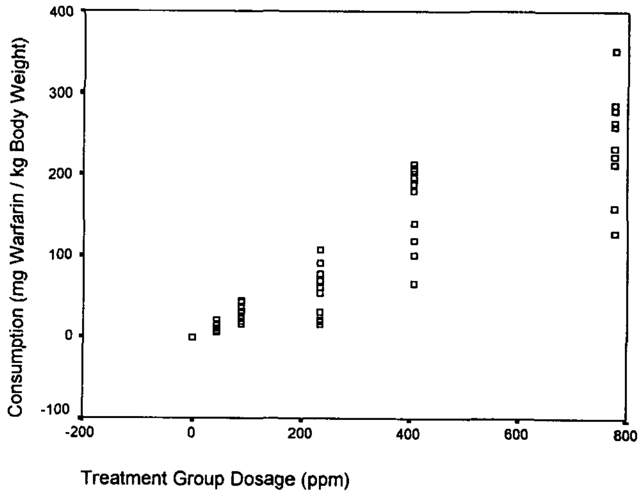

Figure 2. Consumption of warfarin (mg/kg body weight) by prairie dogs fed six different concentrations of warfarin. Prairie dogs were fed warfarin bait in their respective treatment groups for 15 days. Each square represents total consumption of warfarin of one prairie dog.

After the exposure and post-test observation periods were concluded, treatment group mortality was calculated (Table 1). Interestingly, the 777.6 ppm group did not produce 100% mortality like the 407.0 ppm treatment group below it. One male and one female survived. Further investigation revealed that the female prairie dog had eaten only 186.1 mg of warfarin/kg body weight and lost 267 grams of body weight. The male ate only 128.6 mg of warfarin/kg body weight and lost 146 grams of body weight. The female and male ate 43.3 and 121.9 mg of warfarin/kg body weight less than the average of each sex. The female lost 38 grams more than the female mean, and the male lost 24 grams less than the male mean.

According to the efficacy data presented, a computer analysis from "Probit" gives an LC_{50} value of 97 mg/kg body weight. The LC_{90} of the prairie dogs was calculated at 831 mg/kg body weight. Other Probit analyses were performed because of the 80% efficacy achieved in the highest treatment group. One was performed without the 777.6 ppm group and another was performed with 100% efficacy in the 777.6 ppm group. These alternate analyses showed similar LC_{50} values of 94 and 93 mg/kg body weight, respectively. However, the LC_{90} of both of the alternate analyses was much lower, 441 and 376 mg/kg body weight, respectively.

The prairie dog weights in each treatment group were recorded at the beginning of the exposure period. The overall body weight of the prairie dogs was 897 grams. Mean body weights of prairie dogs across treatment were similar (F=0.657, $\underline{P}$=0.658) as were the variances (L=0.545, $\underline{P}$=0.741).

Table 1. Treatment group mortality and mean and range of warfarin consumption per treatment group.

Concentration (ppm)	N	Mortality (%)	Mean Warfarin Consumption mg a.i./kg Body Weight (Range)
Control (0)	10	0	0
44.8	10	30	13.73 (6.30- 21.52)
89.5	10	50	29.85 (16.27- 43.31)
233.0	10	60	55.31 (15.99-107.65)
407.0	10	100	161.42 (65.08-208.16)
777.6	10	80	239.94 (128.63-352.40)

The mean body weight of the animals decreased in all groups except the control group. Table 2 shows the body weight loss or gain according to treatment group, male, and female. Variances among the treatment group showed no significant difference ($L=1.497$, $p=0.208$). As a result, analysis of variance indicated treatment means were different ($P<0.000$). Weight loss from consumption of the treated baits was significantly different from consumption of the untreated control bait (Tukey's $HSD=1.000$, $P<0.05$).

The necropsies showed small to large amounts of hemorrhaging, independent of the treatment dose. During and after the exposure period, hemorrhaging was observed in the nose, eye, mouth, stomach, liver, intestines, cecum, kidneys, anus, heart, lungs, brain, and subcutaneous and neck regions. The hemorrhaging was so extensive in seven animals, the abdomen (5), thorax (1), or subcutaneous (1) became pooled with blood. Twenty-nine of 32 prairie dogs that died during the test were observed to have extensive fat in the abdominal subcutaneous or within the abdomen. Also, fat was present in the thoracic region in 25 of 32 prairie dogs. Six grams fat was observed from around the heart of one prairie dog.

Using a validated laboratory method, whole body analysis of the prairie dogs resulted in a range from 0.080 to 6.072 ppm in the 50, 250, and 1,000 ppm treatment groups (Table 3).

The warfarin accumulation within the tissue is correlated to the treatment group ($r=0.709$). The mean days to death of the prairie dogs used for the tissue analysis in the 44.8, 233.0, and 777.6 ppm treatment groups is 11, 10, and 18.

Also, using a validated laboratory method, concentration verification, laboratory stability, and freezer storage stability of all treatment group warfarin baits were calculated. The t-test showed there was no significant difference between the same treatment levels with the three different samples taken.

Table 2. Body weight[1] loss or gain from the study initiation to termination or time of death. The control group is the only group which gained weight. All other treatment groups showed a general increase in weight loss as the treatment group dosage increased.

Treatment Group	Mean Treatment Group Loss/Gain (g)	Mean Male Loss/Gain (g)	Mean Female Loss/Gain (g)
Control	31.2	51.4	11.0
44.8	-77.0	-111.2	-42.8
89.5	-80.7	-110.8	-50.6
233.0	-112.7	-118.2	-107.2
407.0	-94.7	-128.2	-61.2
777.6	-142.2	-170.2	-114.2

[1]Body weight calculations were taken from Day 0 of the feeding test and at study termination or at time of death.

Table 3. Concentration of warfarin within the whole body tissue of the prairie dogs of treatment groups 44.8, 233.0, and 777.6 ppm, respectively. Animals were chosen at random to be analyzed from animals that had died during the test. The sample identification denotes the sex [male (M) or female (F)], animal number, and sequence of sample used from extraction procedure.

Sample Identification	Concentration (ppm)
M13A	0.091
F17A	0.631
F18A	0.080
M32A	1.495
M34C	1.528
F35A	0.509
M51A	1.139
M52A	6.072
F56A	2.131

DISCUSSION

The results show the physiological variation in the reaction to the different treatments of warfarin baits. Even with the increased amount of warfarin in the higher levels of bait, the 777.6 ppm treatment group failed to produce 100% mortality like the treatment group below it (407.0 ppm). One prairie dog of each sex survived. The male ate much less warfarin bait and lost less weight than the average prairie dog within the same treatment group. The female ate slightly less, but lost much more body weight than the average female within the same treatment group. It is believed that these two individuals survived because of their physiological reactions to the warfarin, possibly involving higher metabolism of the warfarin or a greater ability to synthesize vitamin K from gut bacteria—the antidote for warfarin poisoning (Hadler and Buckle 1992). Mortality is expected to be variable. Physiological difference within an animals species is common. For example, LD_{50} tests predict the required dosage to kill 50% of the population from a range of responses of hypersusceptibility to levels of appeared resistance to a certain chemical compound. Adjustments in application rates are made for such a variability in susceptibility.

The initial effects of the warfarin appear to be independent of treatment group dosage. The final response, mortality, is the factor which varies most. The two extremes of warfarin consumption, 6.3 and 352.4 mg warfarin/kg body weight, caused death in both cases. Some of the lower treatment groups, even with continuous no-choice feeding, failed to cause sufficient trauma to the prairie dogs to result in death. This is why higher treatment dosages must be used for ample control.

The metabolism of the prairie dogs appears to be variable, requiring different amounts of feed to supply themselves with enough nutrients. It is shown that there is no statistical significant relationship between the size of the prairie dog and the amount of bait eaten. The range of the body weights of the prairie dogs was between 676 and 1226 g. It was expected that the larger prairie dogs would eat more bait compared to the smaller animals, but this was not the case. There was only a small relationship between these two factors. Varying factors which could be affecting the prairie dogs are stress from laboratory holding and close physical environment to humans. Also, these prairie dogs were captured in late fall. They were probably storing nutrients for the upcoming winter in the form of fat. The larger animals could have had sufficient supplies of nutrients while the other smaller prairie dogs had to continue foraging to supply themselves with sufficient nutrient stores.

Statistical tests show that the control group is significantly different from the other treatment groups because of the larger amount of bait eaten by the control prairie dogs. This difference could be conceived as a palatability problem because of the difference in consumption from the control group, but most likely, this is a negative response from the warfarin. Warfarin poisoning signs appeared at a similar time (days 5 to 11) with no dose response evident. In addition, the warfarin was causing similar decreases in consumption throughout the treatment groups, again, no dose response was apparent. The warfarin is causing illness in all treated groups at a similar time, resulting in a similar decreased consumption.

Statistical analysis of the warfarin consumption displayed a high correlation coefficient. This indicates that as the treatment dosage increases the amount of mg warfarin/kg body weight will increase. Since the ingestion of warfarin did not decrease at the higher treatment levels, no palatability problems existed. Meehan (1984) reports higher warfarin treatments as being unpalatable, but to correct this problem, a high purity of warfarin was used and the taste was disguised with feed additives.

Prairie dogs used in the test were randomized into treatment groups to achieve an unbiased design which the statistical tests showed. Resulting body weights taken at time of death or at test termination revealed significant body weight loss throughout the exposure and post-test observation period.

Nearing the end of the exposure period, the prairie dogs were not eating much bait because of their warfarin-induced sickness. For example, fat and muscle are the only components which could be slowly lost. Fat was a large component of many prairie dogs that were necropsied at the end of the study. The necropsies revealed small to large amounts of hemorrhaging depending upon the individual. Fat was very common in the abdominal and thoracic cavities as well as in other areas. Fat, which is partly composed of vitamin K, could have been used for the metabolism of the warfarin. Vitamin K, a fat soluble vitamin could have been supplied to the liver for the metabolism of warfarin and reversal of the anticoagulant action.

In a similar Genesis Laboratories, Inc. study with prairie dogs, a factor believed to be the cause of the lack of efficacy was presence of alfalfa cubes. Two prairie dogs died and only three observations of warfarin signs were observed. According to the United States-Canadian Tables of Feed Composition (1982), dry alfalfa can have as high as 14.2 mg of fat-soluble vitamin K per kg. According to Donoco and Haft (1976), and Seegars and Walz (1986), vitamin K is needed by the liver to produce prothrombin (factor II), a major component of the blood clotting mechanism.

Other factors directly involved with vitamin K are the factors VII (serum prothrombin conversion accelerator), IX (plasma thromboplastin component), and X (Stuart-Prower factor). In short, these factors, along with factor II, are most important in beginning the clotting system, which is often referred to as a clotting cascade. This procedure has positive feedback which continues to amplify the reaction intensity. When this cascade is inhibited by warfarin, the result is a failure in blood coagulation (Church and Pond 1988).

The calculated prairie dog LC_{50} places this species in close proximity to the other rodents listed above. The calculated LC_{90} (831 mg/kg) seems to be very high because of the survivors in the 777.6 ppm treatment group. If the 777.6 ppm treatment group had 100% mortality, the calculated LC_{90} would have been 376 mg/kg body weight, less than one-half of the actual. The apparent large range of physiological differences of the prairie dogs, therefore, require a higher dosage to achieve high mortality.

With the removal of the alfalfa cubes in the present study, high mortality was achieved in the higher treatment groups demonstrating diet may be an important factor in warfarin efficacy.

In several cases in study 96018, individuals in the lower treatment groups showed a recovery from the warfarin administration. In addition, between days 11 and 15, almost no bait was eaten, exposing the animals to only 10 days of feeding. Prairie dog M23 lost 185 grams (21% of its initial body weight) over the 25 days of test substance exposure and post-test observation period, leaving the animal very thin. The vitamin K in the fat could have provided enough nourishment throughout this period (Church and Pond 1988). To illustrate, vitamin K is fat soluble and is able to be stored within fat along with vitamins A, D, and E (Church and Pond 1988; Machlin 1984). This allows consumption of vitamin deficient diets over a longer period of time before deficiency signs appear, compared to water soluble vitamins (C, B6, B12, thiamin, and riboflavin).

This could be a reason for the marginal recovery of M23 and the ability of many others to sustain themselves. If vitamin K is stored within the fat reserves of the prairie dogs, which are very extensive, the vitamin K could be metabolized from the fat as an antidote to warfarin.

Vitamin K can also be replaced by gut bacteria (Hadler and Buckle 1992). Bacterial synthesis of vitamin K has also been documented to be absorbed in the lower part of the intestinal tract where the bacterial population is greatest (Machlin 1984). Specifically, vitamin K is absorbed in the large intestine of mammals sufficiently enough to prevent deficiency symptoms when presented a vitamin K deficient diet (Hollander ****).

It would appear with vitamin K being acquired from gut bacteria and the fat in this study, there would be a sufficient supply of vitamin K to produce an antidote. The resulting deaths increased as the concentration level increased, but there was death caused by a large range of warfarin consumption. The two extremes of warfarin consumption, 6.3 and 352.4 mg warfarin/kg body weight, caused death in both cases. The higher warfarin consumption values could be individuals that are metabolizing the warfarin more efficiently than the others. If they were not, more mortality in all treatment groups would be expected.

Certain application techniques can be used to help increase the mortality of the prairie dogs. First, since fat is known to store vitamin K, an antidote to the warfarin, it would be beneficial to eliminate periods of baiting when the prairie dogs are in the process of storing nutrients for winter survival. Second, if bait can be applied when dietary vitamin K is low, an increased mortality could be expected. Using these ideas in conjunction, the significance of vitamin K from the diet and fat reserves must be considered to produce an effective antidote. These ideas signify the pertinence of applying the bait during a period of low vegetative biomass and quality, and when the animals have a low fat content/body weight—early spring.

The tissue analysis resulted in a high correlation between warfarin consumption and tissue accumulation, but the evident variation could be explained by differences in bait consumption and physiology of the prairie dog. The mean days to death of the animals in the tissue analysis is so variable that again, the physiological differences in the prairie dogs is displayed.

CONCLUSIONS

The highest mortality in this study was found to be 100% at the 407.0 ppm level. The highest concentration of 776.7 ppm was not the most efficacious (80%), showing the differences in prairie dog physiology. The fat and dietary vitamin K have the ability to provide an antidote to the warfarin bait which must be considered into a baiting schedule specific to these parameters. At least a 407.0 ppm bait should be used to control less susceptible prairie dogs.

Prairie dog tissue samples yielded residue levels which increase as the treatment group dosage increases. The technique used for mixing the bait repeatedly produced homogeneous batches with all treatment levels. All concentrations of the warfarin bait are stable in the laboratory environment.

The control of the black-tailed prairie dog is an important issue which influences many other animal population. Where prairie dog control is necessary, a warfarin bait could provide an alternative to other baiting practices. The effects of warfarin are easily reversible which is an important consideration in human and non-target safety.

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EFFECTS OF TASTE STIMULI (QUININE AND SUCROSE) IN PELLETED, GRANULATED, AND WAX BLOCK BAITS ON FEEDING PREFERENCES OF NORTHERN POCKET GOPHERS (*THOMOMYS TALPOIDES*)

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ABSTRACT: A two-choice, taste preference study was conducted using 18 northern pocket gophers to evaluate pelleted sorghum, granulated sorghum, and wax block baits containing either 0.01 to 0.05% quinine or 0.10 to 5.0 % sucrose. Bait consumption was significantly higher across treatments ($P \leq .001$) for granulated sorghum, followed by pelleted sorghum, and wax blocks. Gophers also showed a high frequency of moving the granulated bait in their cheek pouches to be deposited at alternate locations within their cages. Although increasing sucrose concentration did not produce significantly ($P \geq .10$) enhanced consumption for any of the baits, a trend toward increasing preference with increased concentration was noted for the wax block bait. During quinine tests, bait consumption was again significantly highest ($P \leq .01$) for granulated sorghum followed by pelleted sorghum and wax block. Quinine treatment also failed to significantly ($P \geq .10$) alter bait consumption across the tested concentrations. However, there was a minor trend toward decreasing preference with increasing concentrations in the wax block group. Data indicated that pelleted bait had the advantage of producing more consistent consumption levels without the animals carrying bait in their cheek pouches for caching and subsequent spillage. Although the wax block baits were most influenced by the taste treatments, consumption levels were extremely low. In comparison with most wild rodent species, northern pocket gophers were found to be insensitive or indifferent to both taste stimuli over a wide concentration range.

KEY WORDS: pocket gophers, baits, preference, taste, sucrose, quinine, *Thomomys talpoides*

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INTRODUCTION

In the Pacific northwest, northern pocket gophers (*Thomomys talpoides*) have caused extensive damage to newly reforested areas (Borrecco and Black 1990), and have been cited as the major vertebrate pest species on national forest lands (Evans 1987). The development of a highly attractive bait material for the control of damage by this species could lead to improved baiting efficacy along with lowered levels of toxicant needed, or to the more efficient oral delivery of non-lethal control agents such as reproductive inhibitors (Miller 1997). Irritants or taste repellent substances applied to food sources could also have a potential for retarding pocket gopher re-invasion rates after control operations similar to the demonstrated repellent effects of predator odors (Sullivan et al. 1990).

Numerous food habits studies (Ward and Keith 1962; Ward 1977; Cox 1989; Burton and Black 1978; Cox 1989; Bonar 1995) have indicated that there are several naturally preferred plants (e.g., mountain dandelion root, onion grass bulbs, lupines) that could be exploited as sources of flavor extract additives for dry bait material. Seasonal aspects of these food habits should also be considered when attempting to improve bait palatability. The selection of the appropriate preference test method and food base material should be based on reliable and sensitive laboratory preference test procedures with bait flavor agents added at controlled concentrations. The current study was an initial investigation of three base materials and two standard taste substances chosen to represent sweet and bitter taste (sucrose and quinine), each evaluated at three concentrations. Many plant species contain these or similarly-flavored substances in varying concentrations throughout their root, leaf, and stem systems.

METHODS

Animals

Thirty pocket gophers (*Thomomys talpoides*) were trapped near Wellington, Colorado and transported in a temperature-controlled vehicle to an animal research holding facility. They were then transferred to individual stainless steel cages (34 x 18 x 18 cm) with wire mesh floors (13 mm) after being dusted for ectoparasites with a pyrethrum-containing flea and tick powder. Eighteen male gophers were selected for the food base taste preference tests. All animals underwent a 14-day quarantine period before they were tested. Throughout the quarantine and test period, the gophers were maintained on carrots, apples, alfalfa cubes, and Purina® laboratory rodent chow pellets with water available *ad libitum*.

Bait and Taste Stimulus Materials

Pelleted milo baits were formulated with ground sorghum, cellulose, and Avicell®. The sorghum was first ground to a fineness of flour that could pass though a 0.5 mm screen. For sucrose AR® and quinine hydrochloride additives (Mallinckrodt, Inc., Baxter, Scientific Products, Denver, CO), the materials were throughly mixed in dry form with a commercial electric food mixer (Kitchen Aid) in 1000 g batches for five minutes before water was added. The mixture was then further stirred in the processing machine for another 10 minutes before being run through a pelleting machine and dried in a laboratory oven at 65°C. The granulated material was made in an identical manner except for the pelleting operation. Instead, the mixed milo material was oven dried and broken apart and collected as bait material that passed through course sieves between 2 mm and 10 mm. Wax block baits were made from a commercial candle wax (Chevron No. 139) that was brought up to melting point for mixing with taste ingredients and then allowed to cool and solidify in 2 cm diameter x 3 cm cylindrical molds. Molded wax baits were tested in this form in the food preference cups.

Food Containers

Tested bait products were evaluated in two stainless steel food cups per each cage (total of 36 cups). These were held in place by screw-type pinch clamps attached to the front of the cages. All cups were weighed and tared so that the initial amount of bait material offered to each gopher was 30.00 g per cup.

Preference Test Procedure

Briefly, the preference testing technique involved exposing the foods (30 grams quantities) in each of two 5-cm diameter by 4-cm deep stainless steel cups spaced 5 cm apart inside the front portion of the individual cages. The initial test food (whole milo) was offered to the gophers for a 2-hour period after a previous 4-hour food deprivation interval (8:00 hr to 12:00 hr MST). Food consumption was determined by weighing the contents of each food cup at the end of each daily feeding trial. After the 2-hour test, animals were allowed to feed *ad libitum* for 18 hours before the next food deprivation interval. Because the animals were relatively inactive in their home cages, this mild food deprivation was assumed to pose only a slight level of stress. The animals were weighed every day to monitor for potential body weight loss problems or other signs of poor health. Before preference testing began, animals were acclimated to feeding on the whole milo from the food cups for four days.

Food Base Selection

This phase of the work was designed to determine which of the three food base formulations would generate the most sensitive and reliable taste preference data with northern pocket gophers in the laboratory.

Pocket gophers were randomly assigned to three groups (n=6/ea) to receive one of the bait materials consisting of: pelleted milo, granulated milo, or wax block. One food cup containing 30 g of one of the three standard food bases and a second (alternate-treated) cup containing the same food base plus sucrose treatment at the 0.1, 1.0, or 5.0% levels were offered to the animal groups successively in ascending order over two-day intervals. All animals were preference tested for 2 hr each day in succession for each concentration, with treated versus untreated food cup positions alternated daily. The same procedure was then used for two-choice preference tests of quinine hydrochloride treatments at 0.01, 0.1, and 0.5% levels presented successively in ascending order. Percent preference values for treated baits were calculated by generating T/(T + U) fractions, with T equal to the treated bait consumed and U equal to the untreated bait consumed (spillage values subtracted from each separately), and multiplying by 100.

Data Analyses

Data for mean treated bait consumption and percent preference for treated bait for each animal were analyzed as two-way repeated measures analyses of variance for each taste substance with food base (3) and additive concentration (3) as the main factors. When significant ($P \leq 0.05$) differences were detected for a factor, Duncan multiple range tests were used for comparisons of individual means.

RESULTS AND DISCUSSION

Sucrose

As indicated in Table 1, there was relatively more consumption of the granulated bait material compared to the pelleted sorghum and wax block baits throughout the tests at the higher sucrose concentrations (i.e., 1.0% and 5.0%). However, consumption of both treated and untreated granulated bait increased at these higher sucrose levels, thus reducing the degree of preference the animals showed for sucrose treatment. One explanation of this effect was that animals offerred granulated bait form consumed more bait, but also picked bait up in their cheek pouches and carried the material to different locations within their cages. Sometimes there was mixing of the two baits by the gophers in the food cups by this means. This factor could have produced some extra measurement error, but was not verified as a major error source with food color added to the two bait materials.

An analysis of variance showed no significant effect for sucrose concentration ($F=1.936$; $df=2,34$; $P>0.10$). There was a significant preference among groups for the granulated sorghum bait based on mean treated bait consumption data ($F=8.209$; $df=2,34$; $P<.001$). Based on the two-day means, the granulated material was consumed the most (1.58 ± 1.34 grams) followed by pelleted (0.97 ± 0.40 grams), and finally, wax block bait (0.37 ± 0.62 grams)($p \leq .05$). Based upon the percent preference comparisons, the wax block bait was, however, the most enhanced by the addition of sucrose taste treatments as shown in Figure 1. This tendency, though not reliable from a statistical standpoint ($p \geq .10$) with six animals per group, could possibly indicate that the northern pocket gopher's preference threshold for sweet taste was lowest when offered in the wax block form. Conversely, the bait enhancer effect potentially generated by sucrose could have been partially masked in baits when offered in the granulated and the pelleted forms.

Quinine

Granulated sorghum was again consumed the most (1.56 ± 1.05 grams) followed by pelleted (0.69 ± 0.28 grams) and wax block baits (0.13 ± 0.25 grams) (see Table 2). This effect was shown to be statistically reliable ($F=19.69$; $df=2,34$; $P<.01$) and was sustained on the second test day as shown in Table 2. Analysis of variance of treated bait consumption data indicated no significant change in bait intake as concentrations were varied from 0.01 to 0.50 percent quinine ($F=0.079$; $df=2,34$; $P>.924$). In addition, the degree of preference or repellency generated by bitter-tasting quinine was not significant statistically in pocket gopher two-choice tests for any of the three bait forms (Figure 2).

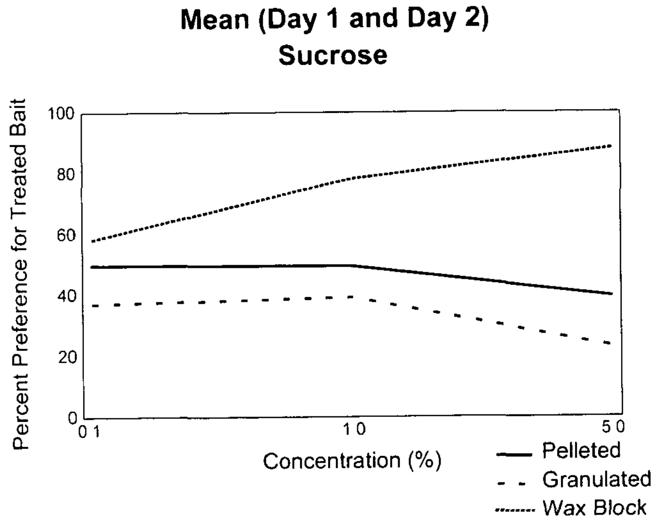

Figure 1. Mean percent preference for treated versus untreated bait material for three sucrose concentrations in three bait bases.

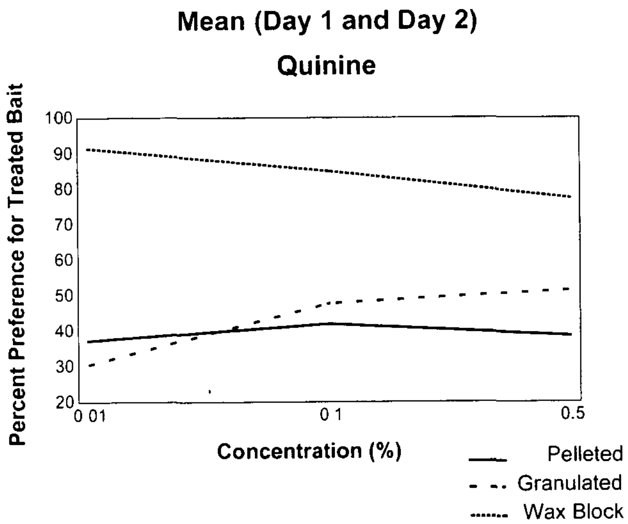

Figure 2. Mean percent preference for treated versus untreated bait material for three quinine concentrations in three bait bases.

Although again not significant with only six animals per group, there was a trend toward decreasing preference for the wax block baits treated with higher levels of quinine (Figure 2). This could have been an indication that pocket gophers, when minimally food-deprived for 4 hours, tended to have more sensitivity to bitter quinine taste in the flavored wax block bait form compared to the pelleted and granulated sorghum bait forms.

It is interesting that pocket gophers show discrimination among plant and root materials (Cox 1989) in their specific habitats. They are, however, much less affected by quinine and sucrose taste additives when compared with wild Norway rats, ground squirrels and chipmunks (Hani et al. 1997). The range of levels tested in this study have been demonstrated to produce extreme changes in preference for most above-ground rodents and squirrels as contrasted to the shallow curves generated in the present study (i.e., Figures 1 and 2).

Bait Development Implications

Pocket gopher baiting efficacy with a mechanical burrow builder has been evaluated (Sargent and Peterson 1963) for plains pocket gopher (*Geomys* spp.) control using several different grain bases (i.e., cracked corn, milo, oats, soybeans and wheat). The only difference in detected field bait acceptance by *Geomys bursarius* was during summer months when soybeans were less accepted. Mountain pocket gophers (*Thomomys* spp.) have not been reported as having an equal acceptance of these grain baits, but, most likely all would be readily accepted also. With non-grain baits (e.g., carrots, prunes, raisins), pocket gophers tended to select high moisture content items rather than items of a particular size as bait material (Miller and Howard 1951). Whole carrots were taken to nest and caching chambers in the burrows without being broken or chewed into smaller particles to be stored in the gopher's cheek pouches.

The current study has confirmed that mountain pocket gophers can carry and store certain forms of bait in their cheek pouches, particularly when offered in the granulated form. Although consumption was also highest for this material, a reliable estimate of the amount consumed by individual gophers would be quite difficult to predict and measure under field conditions. The pelleted milo had an advantage in this respect and could prove superior to whole milo in terms of consistency of consumed treatment level per bait particle. Wax block was poorly accepted and would have to be mixed with a suitable grain such as milo or wheat to achieve improved utility in baiting applications. The wax material does have an advantage, however, in terms of capabilities for bait flavor enhancement to improve bait acceptance.

Extracts from preferred plant materials (e.g., mountain dandelion [*Agoseris*) roots, onion grass [*Melica*) bulbs, lupines [*Lupinus*], western yarrow [*Achilia*]) could be potentially added to wax block material or pellet bait formulations to further improve acceptance by mountain pocket gophers. Advantages of high acceptance include: lowered levels of toxicant needed for control, improved baiting efficacy, and, possibly, reduced hazards to potential non-target species.

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Table 1. Daily consumption level comparisons in grams for northern pocket gophers offered pelleted, granulated, and wax block baits ($\bar{x} \pm$ s.d.). Three concentrations of sucrose-treated (T) versus untreated (U) material were tested in separate animal groups for each type of bait.

Day 1 Group		0.1%	Concentration 1.0%	5.0%
Pelleted	(T)	1.32 ± 0.07	1.09 ± 0.57	0.81 ± 0.35
Pelleted	(U)	1.14 ± 0.04	0.90 ± 0.25	1.17 ± 0.37
Granulated	(T)	0.89 ± 0.42	2.78 ± 1.98	2.21 ± 2.18
Granulated	(U)	0.87 ± 0.56	1.93 ± 3.32	2.38 ± 1.77
Wax Block	(T)	0.13 ± 0.45	0.57 ± 0.71	0.39 ± 0.69
Wax Block	(U)	0.17 ± 0.21	0.10 ± 0.19	0.10 ± 0.08
Day 2 Group		**0.1%**	**Concentration 1.0%**	**5.0%**
Pelleted	(T)	1.12 ± 0.45	0.72 ± 0.38	0.67 ± 0.41
Pelleted	(U)	1.31 ± 0.10	1.00 ± 0.13	1.09 ± 0.23
Granulated	(T)	0.76 ± 0.43	1.43 ± 0.97	2.59 ± 2.48
Granulated	(U)	2.46 ± 2.11	5.96 ± 5.86	6.95 ± 5.80
Wax Block	(T)	0.44 ± 0.86	0.20 ± 0.34	0.59 ± 0.95
Wax Block	(U)	0.16 ± 0.44	0.08 ± 0.05	0.02 ± 0.00

Table 2. Daily consumption level comparisons in grams for northern pocket gophers offered pelleted, granulated, and wax block baits ($\bar{x} \pm$ s.d.). Three concentrations of quinine-treated (T) versus untreated (U) material were tested in separate animal groups for each type of bait.

Day 1 Group		0.1%	Concentration 1.0%	5.0%
Pelleted	(T)	0.57 ± 0.04	0.88 ± 0.35	0.61 ± 0.21
Pelleted	(U)	1.18 ± 0.28	1.01 ± 0.20	0.82 ± 0.27
Granulated	(T)	1.32 ± 1.08	1.64 ± 0.78	0.82 ± 0.84
Granulated	(U)	2.70 ± 2.31	2.57 ± 2.98	0.73 ± 0.86
Wax Block	(T)	0.20 ± 0.28	0.16 ± 0.32	0.08 ± 0.10
Wax Block	(U)	0.03 ± 0.03	0.02 ± 0.02	0.02 ± 0.01
Day 2 Group		**0.1%**	**Concentration 1.0%**	**5.0%**
Pelleted	(T)	0.78 ± 0.39	0.61 ± 0.38	0.54 ± 0.32
Pelleted	(U)	1.08 ± 0.35	1.02 ± 0.34	1.02 ± 0.27
Granulated	(T)	0.92 ± 0.30	1.35 ± 0.58	0.75 ± 0.34
Granulated	(U)	2.35 ± 1.89	1.03 ± 1.10	0.75 ± 0.76
Wax Block	(T)	0.24 ± 0.32	0.13 ± 0.21	0.03 ± 0.20
Wax Block	(U)	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.01

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MANAGEMENT OF RED SQUIRREL FEEDING DAMAGE TO LODGEPOLE PINE BY STAND DENSITY MANIPULATION AND DIVERSIONARY FOOD

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ABSTRACT: The red squirrel (*Tamiasciurus hudsonicus*) feeds on the vascular tissues of sapling lodgepole pine (*Pinus contorta*) during spring periods in forests of interior British Columbia and Alberta, Canada. This damage may lead to mortality and reduced growth of crop trees in managed stands. Manipulation of stand density by pre-commercial thinning to densities <1,000 stems/ha is an effective method to lower squirrel populations and feeding damage. Lowering stand density enhances the growth of crop trees, and understory herbs and shrubs as wildlife habitat, while protecting trees from squirrel feeding. This approach has been successful in several forest ecological zones. An alternative management tool is provision of diversionary food (sunflower seed) for those stands susceptible to feeding damage, and where stand thinning has already been completed. Diversionary food can be applied aerially and is very cost effective for protecting managed stands. These techniques may be used to maintain or even enhance species diversity of small mammal communities in those forest stands requiring protection.

KEY WORDS: diversionary food, forest management, lodgepole pine, pre-commercial thinning, red squirrel, small mammals, species diversity, stand density, sunflower seeds, wildlife habitat

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INTRODUCTION

Three species of squirrels inhabit forests of the Pacific Northwest (PNW) of North America. The Douglas squirrel or chickaree (*Tamiasciurus douglasii*) is restricted to the west coast from southwestern British Columbia south through the Sierras to northern Baja California. The red squirrel (*T. hudsonicus*) ranges throughout the inland PNW and across the boreal and sub-boreal forests of Canada and the northeastern U.S. (Banfield 1974). Both of these squirrels have similar habits and are active throughout the winter. The western grey squirrel (*Sciurus griseus*) is found in mixed coniferous-deciduous forests along both sides of the Cascade Range in western Washington, western Oregon and northern California (Carraway and Verts 1994).

All three species of tree squirrels strip bark from the boles of conifers to feed on the exposed sapwood (Lawrence et al. 1961; Baldwin et al. 1986; Sullivan and Sullivan 1982; Sullivan 1998). Trees in the 20- to 60-year age classes generally sustain the greatest injury. Squirrels remove small strips of bark and then feed on the vascular tissues on the exposed sapwood. The sapwood and short strips of discarded bark (3 by 8 cm) that accumulate on the ground under the injured tree may have scattered toothmarks. These bark strips readily distinguish squirrel work from similar crown-girdling injuries by porcupine (*Erethizon dorsatum*) and woodrat (*Neotoma cinerea*). Most barking damage by squirrels occurs in spring and early summer during the early part of the growing season. The red squirrel may seriously damage crop trees in pre-commercially thinned stands of lodgepole pine (*Pinus contorta*) in interior regions of the PNW (Brockley and Sullivan 1988; Sullivan et al. 1994).

HABITAT MODIFICATION

There are two major questions associated with the use of habitat modification or alteration as a tool to reduce wildlife damage in forest and agricultural areas:

1) Can we modify habitat to reduce damage?
2) Can habitat modification, which reduces damage by the target problem species, actually benefit other non-target species such that diversity of the overall wildlife community is maintained or enhanced?

Managing forests to produce a desirable mix of forest resources, including timber and wildlife, requires an understanding of how animals respond to habitat. Management strategies aimed at long-term population change are most likely to succeed if they alter habitat quality, quantity, or availability. Modification of habitat to reduce populations of one target species likely also changes habitat quality or quantity for other wildlife species (McComb and Hansen 1992).

Principal components of habitat for a given wildlife species include food quality and quantity, and cover for nesting (reproduction), thermal (maintenance of body temperature and physiology), and security (escape from predators) needs. Natural resource managers can manage habitat to control a problem species by reducing food quality, quantity, or availability while also reducing the quality, quantity or availability of cover. This strategy can lead to significant reductions in habitat quality for the pest species (McComb and Hansen 1992).

An alternative approach is to increase cover through enhancement of forest stand structure (e.g., snags and slash piles) to enhance predator abundance, and increase food by way of providing a diversionary food source. This latter approach is designed to temporarily satisfy part, or a majority, of the food requirements of a problem species in a localized area. Consequently, feeding damage should be reduced and the problem species should be attracted or concentrated away from the crop to be protected.

The major objective of this paper is to discuss the use of operational tools: 1) stand thinning (reduce food and cover); and 2) diversionary food (increase food), as means of habitat modification to reduce feeding damage to lodgepole pine by red squirrels. A secondary objective is to describe responses of non-target small mammal communities to these treatments.

METHODS

Study Areas

The study areas for research and development of the use of: 1) variable stand density; and 2) diversionary foods, to manage red squirrels in young lodgepole pine forest, are described in Sullivan et al. (1996) and Sullivan and Klenner (1993), respectively.

Variable Stand Density

A low (500 stems/ha), medium (1,000 stems/ha), and high (2,000 stems/ha) density was investigated at each of the Penticton Creek, Kamloops, and Prince George study areas in the south-central interior of British Columbia, Canada. This operational scale experiment was initiated with pre-commercial thinning in the fall of 1988 (1989 at Kamloops) to test the influence of variable tree density on squirrel populations and feeding damage. All stands in these areas had a history of chronic damage by squirrels with mean values ranging from 43% to 70% of trees with feeding injuries. Squirrel populations were live-trapped at two-week intervals during May to August (damage period) 1989, 1990, and 1991 (1990 and 1991 at Kamloops). Feeding damage to sample crop trees was measured annually in August 1989 to 1993. See Sullivan et al. (1996) for details of methodology.

Diversionary Food

This operational experiment was conducted in 1990 at the Bigg Creek study area (Sullivan and Klenner 1993) to assess the influence of manually applied sunflower seed on squirrel populations and damage to lodgepole pine crop trees. Two control stands and two treatment stands were established at Bigg Creek with two additional control stands at McGregor Creek, two distinct study areas near Vernon, B.C. Sunflower seeds were distributed manually on the ground at 30 m intervals, with about 1 kg of seed in each pile, in the treatment stands on May 15 and June 16, 1990. Squirrel populations were live-trapped at two-week intervals from May to August 1990. Feeding damage to sample crop trees was measured in August 1990. See Sullivan and Klenner (1993) for details of methodology and Sullivan (1992) for details of operational aerial application of sunflower seed.

Small Mammal Communities

In each of the three stands in the variable stand density experiment and two additional stands (unthinned and old growth lodgepole pine, installed for comparative purposes) at each study area, and in each of the two control and two treatment stands in the diversionary food experiment, a 1 ha live-trapping grid with 49 (7 x 7) trap stations at 14.29 m intervals with one Longworth live-trap at each station was established. Small mammal populations were sampled at two-week intervals from May to August in 1990 and 1991 for the variable stand density experiment, and in 1990, for the diversionary food experiment. Traps were supplied with whole oats and coarse brown cotton as bedding. Traps were set on the afternoon of day 1, checked on the morning and afternoon of day 2 and morning of day 3, and then locked open between trapping periods. All animals captured were ear-tagged and point of capture recorded. Small mammals were released on the grids immediately after processing. Population density of the common species was estimated using the Jolly-Seber model (Seber 1982) for the variable stand density data, and minimum number alive (MNA) for the one year of data in the diversionary food study. MNA was selected for the latter study because the generally preferred Jolly-Seber estimator became unreliable and impossible to calculate for species with low recaptures of previously marked animals (Krebs et al. 1986).

Small mammal species captured included the deer mouse (*Peromyscus maniculatus*), southern red-backed vole (*Clethrionomys gapperi*), northwestern chipmunk (*Tamias amoenus*), long-tailed vole (*Microtus longicaudus*), meadow vole (*M. pennsylvanicus*), shrews (*Sorex* spp.), and weasels (*Mustela* spp.).

Species diversity was measured by Simpson's index of diversity (Simpson 1949) which is sensitive to changes in the more abundant species. The Shannon-Wiener index of diversity (Pielou 1966) was also used because it is sensitive to changes in the rare species in a community sample. These diversity measures were calculated using Jolly-Seber (variable stand density) and MNA (diversionary food) population estimates for the common species and number of individuals captured for the less abundant species (shrews and weasels). These values were calculated for each trapping period and were then averaged for each summer.

Both studies used a randomized block experimental design with spatial and temporal replication for the regional replicates in the variable stand density study, and spatial replication for the site replicates in the diversionary food study. A randomized-block ANOVA (Zar 1984), which assumes no interaction between the blocks and the levels of treatment, was conducted to test differences in mean numbers of squirrels and feeding damage among treatments in the variable stand density study, and mean species diversity of small mammals among treatments in both studies. Mean numbers and 95% confidence limits were also been calculated for red squirrels and small mammal species (diversionary food study) for each summer in each stand.

RESULTS AND DISCUSSION

Variable Stand Density

Numbers of red squirrels were consistently higher in the medium and high density stands than in the low density stand at Penticton and Prince George (Figure 1). Both the low and medium density stands at Kamloops had significantly fewer squirrels in terms of average abundance than the high density stand (Sullivan et al. 1996). Feeding damage by red squirrels over the period 1989 to 1993 was significantly higher in the high density stands than in either the low or medium density stands (Table 1). Low-density stands appear to provide marginal conditions for these animals because of their reduced protective cover and a possible increased risk of predation. Similarly, reduction in understory shrub cover in young stands may also reduce the incidence of feeding damage by squirrels to pine crop trees (Sullivan et al. 1994).

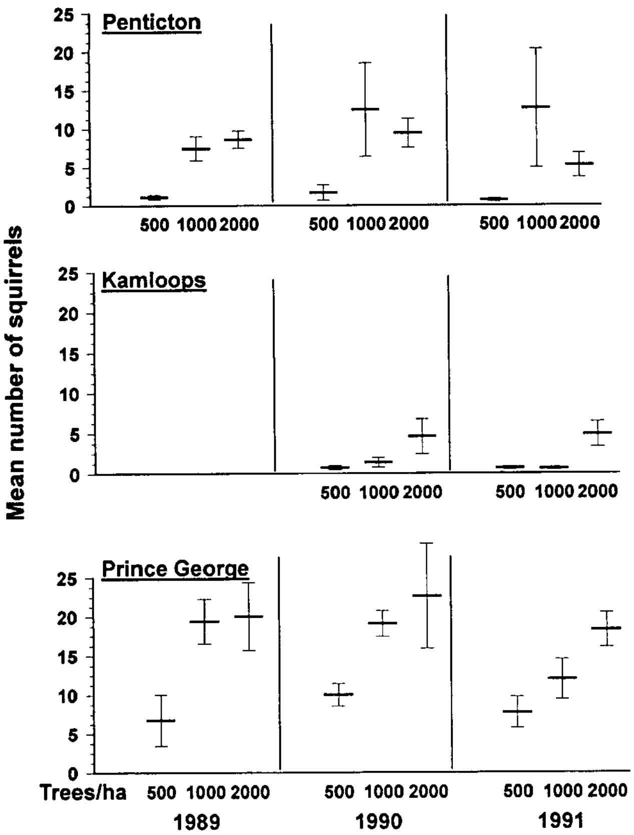

Figure 1. Mean number of red squirrels and 95% confidence limits during each summer in the three stands at each study area for Jolly-Seber population estimates.

Diversionary Food

Red squirrel populations were higher in the treatment than control stands during the May to July feeding period. This difference was particularly pronounced when transient squirrels were included in the analysis, less so when only resident squirrels were considered (Sullivan and Klenner 1993). Squirrel populations in those stands with the diversionary food returned to control levels by August 1990. As discussed by Sullivan (1992) and Sullivan and Klenner (1993), feeding damage to crop trees was reduced significantly in the treatment stands.

This method has considerable potential to reduce damage with minimal disruption of habitat and wildlife. Historically, diversionary foods were perceived as being of limited utility and efficacy, with relatively high costs compared to other techniques. However, the approach is receiving renewed interest because of the movement away from lethal control methods towards more ecologically-based measures. In general, there has been relatively minor use of supplemental feeding for management of problem wildlife because of a lack of information and experimental results. Also, there is the perception that supplemental feeding may favor a local increase in the target population by increasing reproduction and survival, or it may change the behavior of the target animals.

The quality of supplemental food offered is of critical importance. Food should ideally be more palatable than the crop being protected and of similar or lower nutritive value than natural foods. A highly palatable and nutritious food could stimulate increased reproduction and immigration with consequent population increases beyond what the food supplementation program can support. Food must be presented in a way and place so as to be readily fed upon. Much research needs to be done on the quality, quantity, and placement of food. For example, the question of whether or not food should be placed or planted within a crop or reforested area depends on the preference ranking, abundance, and distribution of the supplemental food. It also depends on the feeding characteristics of the problem species and the average size of its natural home range.

The best candidate problem species are those that cause damage predictably and over relatively short periods of time (few weeks or months) because the crop is only susceptible for a short time, or the animal species are in the area or at pest status densities for a limited period. Examples are black bears (*Ursus americanus*) (Ziegltrum and Nolte 1997) and red squirrels which strip

Table 1. Average number of lodgepole pine trees per ha damaged by red squirrels over the period 1989 to 1993.

	Stand Density		
Study Area	500	1,000	2,000
Penticton	9	8	68
Kamloops	28	43	144
Prince George	19	40	74

bark from sapling-pole size timber to feed on vascular tissues during spring months. Other examples are conifer seed predation by the deer mouse (Sullivan and Sullivan 1984), and crop damage by voles (*Microtus* spp.) in no-till fields (Hines 1997), which also occur primarily in the spring. Each of these damage scenarios has an operationally viable diversionary food program to successfully reduce feeding damage to crop plants and trees.

Small Mammal Communities

Species diversity of the small mammal communities was significantly different between stand treatments in the variable stand density study for the Shannon-Wiener ($F_{4,20}$=4.00; P=0.02) and nearly so for Simpson's ($F_{4,20}$=2.50; P=0.08) diversity measurements. In terms of mean values and 95% confidence limits when comparing individual stands and years, there were no significant differences in small mammal diversity between stands at Penticton, except for the community in old growth which was significantly more diverse than that in the medium density stand in 1990 (Table 2). There were no differences between stands in 1991 at Penticton. At Kamloops, small mammal diversity was significantly higher in all thinned stands than in the unthinned and old growth stands in 1990. This trend of higher diversity continued in 1991 for the low and medium density stands. At Prince George, the low and medium density stands had a significantly higher diversity of small mammals than the high density or old growth stands in 1990. In the second year of sampling, all thinned stands tended to have higher diversity of small mammals than either of the unthinned or old growth stands (Table 2).

Evaluation of the response of small mammal communities to application of diversionary food indicated that, except for *M. pennsylvanicus*, there were no consistent differences in abundance between paired control and treatment stands (Table 3). Similarly, there was no difference between control and treatment stands for either Simpson's ($F_{1,1}$0.54; P=0.64) or Shannon-Wiener ($F_{1,1}$=0.62; P=0.62) diversity measurements. Simpson's diversity averaged 0.74 (control) and 0.65 (treatment) and Shannon-Wiener diversity averaged 1.85 (control) and 1.67 (treatment) in this diversionary food study (Table 3).

MANAGEMENT IMPLICATIONS

Stand Protection, Productivity, and Biodiversity

Habitat modification by manipulating stand density of lodgepole pine to <1,000 stems/ha by pre-commercial thinning is an effective method to reduce red squirrel populations and feeding damage in susceptible stands. Lowering stand density enhances growth of crop trees and the alteration of habitat appears to provide marginal conditions for squirrels in terms of protective cover and risk of predation. Thus, both stand protection and productivity can be achieved by stand density manipulation. Feeding damage by squirrels appears to decline as trees reach a dbh of 20 cm. This target dbh will be reached sooner in low density rather than in high density stands, since the widely spaced trees are responding with rapid diameter growth.

Enhancement of understory vegetation (herbs and shrubs) also occurs in heavily thinned stands and when combined with the appropriate crop tree average diameters (e.g., near 20 cm), may contribute to managing forests for biological diversity. This approach includes forestry practices that provide a variety of stand densities, successional stages, tree species, and stand structures in a mosaic of habitats across a landscape (Hunter 1990). Silvicultural practices that can provide a diversity of stand structures (habitats) could help meet the goals of managing for diversity.

Intensive management by stand density manipulation, to reduce squirrel damage, did not negatively affect small mammal communities in terms of species diversity. In fact, diversity of these communities tended to be highest in the low density stands. In addition, the thinned stands tended to have higher diversity overall than the unthinned stands of pine. This result suggests that stand structure in the thinned stands was growing in complexity and, hence, providing microhabitats and habitats for wildlife.

It is important to note that diversity measurements in this study were quantitative rather than qualitative. For example, each stand (or habitat) could have had a completely different set of species regardless of the qualitative measurements, which indicated that one stand had higher diversity than another. All of these communities of species are valuable and must be included in management plans.

Diversionary Food

As discussed by Sullivan (1992), operational application of sunflower seed as a diversionary food is an alternative management tool for those stands susceptible to feeding damage, where pre-commercial thinning or planting has already been completed. Such stands may be part of regular regeneration and silviculture programs, seed orchards, progeny sites, or other installations in a given forest operating unit. Diversionary food can be applied aerially and is very cost effective for protecting managed stands.

The operational cost at the start of this program in 1991 ranged from $40 to $45/ha per year. Since then, this technique has been used operationally to protect several thousand ha of managed stands in the Vernon and Kamloops Forest Districts in the southern interior of British Columbia. Costs have increased slightly to $45 to $50/ha per year, primarily due to fluctuating prices of sunflower seeds. Again, this technique is applied once per year, in the spring, prior to squirrel feeding damage in susceptible stands of lodgepole pine. For example, even if this protection was required annually for 10 years (from ages 15 to 25; up to approximately 20 cm dbh), the cost would be $450 to $500/ha to protect a managed stand investment of up to $3,000/ha.

Application of diversionary food reduced feeding damage by red squirrels with concurrent maintenance of small mammal abundance and diversity in managed stands of lodgepole pine. Similarly, both forest and wildlife objectives can be achieved when using variable stand density to solve a wildlife damage problem.

Table 2. Mean species diversity (Simpson's and Shannon-Wiener) of small mammal communities in the five stands at each area for the variable stand density study (95% confidence limits are given in parentheses).

	Stand Density				
Year and Study Area	500	1,000	2,000	Unthinned	Old Growth
Simpson's Diversity					
1990					
Penticton	0.46 (0.37-0.55)	0.40 (0.34-0.46)	0.40 (0.32-0.48)	0.47 (0.43-0.51)	0.55 (0.48-0.62)
Kamloops	0.64 (0.60-0.68)	0.64 (0.60-0.68)	0.60 (0.56-0.64)	0.33 (0.26-0.40)	0.52 (0.48-0.56)
Prince George	0.65 (0.60-0.70)	0.65 (0.62-0.68)	0.55 (0.53-0.57)	0.61 (0.53-0.69)	0.49 (0.42-0.56)
1991					
Penticton	0.51 (0.45-0.57)	0.53 (0.46-0.60)	0.46 (0.38-0.54)	0.46 (0.36-0.56)	0.58 (0.53-0.63)
Kamloops	0.71 (0.69-0.73)	0.70 (0.64-0.76)	0.56 (0.52-0.60)	0.54 (0.48-0.60)	0.47 (0.35-0.59)
Prince George	0.69 (0.66-0.72)	0.66 (0.62-0.70)	0.65 (0.62-0.68)	0.52 (0.46-0.58)	0.58 (0.52-0.64)
Shannon-Wiener Diversity					
1990					
Penticton	1.18 (0.98-1.38)	0.98 (0.87-1.09)	1.01 (0.83-1.19)	1.10 (1.02-1.18)	1.31 (1.14-1.48)
Kamloops	1.61 (1.44-1.78)	1.65 (1.53-1.77)	1.39 (1.32-1.46)	0.87 (0.73-1.01)	1.09 (1.02-1.16)
Prince George	1.60 (1.44-1.76)	1.55 (1.42-1.68)	1.32 (1.22-1.42)	1.52 (1.34-1.70)	1.22 (1.06-1.38)
1991					
Penticton	1.33 (1.21-1.45)	1.23 (1.05-1.41)	1.21 (1.02-1.40)	1.05 (0.84-1.26)	1.30 (1.17-1.43)
Kamloops	1.80 (1.73-1.87)	1.77 (1.59-1.95)	1.23 (1.12-1.34)	1.27 (1.15-1.39)	1.07 (0.82-1.32)
Prince George	1.63 (1.52-1.74)	1.58 (1.43-1.73)	1.54 (1.41-1.67)	1.28 (1.13-1.43)	1.35 (1.27-1.43)

Table 3. Mean abundance of small mammal populations per ha and species diversity (Simpson's and Shannon-Wiener) of small mammal communities in the control and treatment stands for the diversionary food study (95% confidence limits are given in parentheses).

	Stand			
Species and Variable	Control-1	Food-1	Control-2	Food-2
P. maniculatus	5.00 (2.25-7.75)	3.13 (0.55-5.71)	6.88 (4.04-9.72)	7.25 (3.16-11.34)
C. gapperi	3.25 (1.93-4.57)	0.00	0.50 (0.05-0.95)	0.38 (-0.05-0.81)
T. amoenus	1.88 (0.01-3.75)	3.00 (1.21-4.79)	4.13 (3.00-5.26)	1.75 (1.16-2.34)
M. pennsylvanicus	0.63 (0.20-1.06)	3.63 (1.36-5.90)	1.75 (0.59-2.91)	4.88 (3.58-6.18)
M. longicaudus	3.13 (0.22-6.04)	2.00 (-0.29-4.29)	0.25 (-0.14-0.64)	0.50 (-0.13-1.13)
Sorex spp.	2.88 (1.07-4.69)	2.00 (-0.28-4.28)	1.50 (0.50-2.50)	1.75 (-0.08-3.58)
Mustela spp.	0.00	0.25 (-0.14-0.64)	0.00	0.13 (-0.17-0.43)
Simpson's Diversity	0.78 (0.73-0.83)	0.58 (0.28-0.88)	0.69 (0.64-0.74)	0.72 (0.68-0.76)
Shannon-Wiener Diversity	1.96 (1.57-2.35)	1.54 (0.71-2.37)	1.74 (1.49-1.99)	1.79 (1.70-1.88)

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PORCUPINE DAMAGE AND REPELLENT RESEARCH IN THE INTERIOR PACIFIC NORTHWEST

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ABSTRACT: Porcupines (*Erethizon dorsatum*) rely on trees and shrubs for winter food and can cause serious, localized damage to conifers. Twenty-two percent of ponderosa trees (*Pinus ponderosa*) examined in southeastern Washington were damaged by porcupines. Most damage involved complete girdling of the mid- to upper boles of the larger trees (12 to 30 cm dbh) in the stand. Preliminary repellent trials with captive porcupines suggested that several materials might reduce tree damage, especially predator-associated odors. Field trials are needed to assess efficacy and duration of protection under ambient winter conditions.

KEYWORDS: porcupine, *Erethizon dorsatum*, forest damage, repellents

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INTRODUCTION

Porcupines (*Erethizon dorsatum*) can cause significant localized damage to regenerating conifers in the western United States (Borrecco and Black 1990). They clip or girdle small seedlings, but also gnaw bark from the boles of well established pole-sized trees. They can also cause damage to crops, buildings, and other structures (Schemnitz 1994). Historically, porcupine damage has been controlled by population reduction through trapping, shooting or use of toxic bait (Evans 1987; Schemnitz 1994). However, many of those methods are no longer available or are very restricted in application. There are no registered repellents to reduce porcupine damage in the United States (Schemnitz 1994). Research is needed to develop effective, nonlethal methods to reduce porcupine damage (Evans 1987; Dodge and Borrecco 1992).

Efforts are underway to re-establish woody vegetation on the Palouse Prairie, a large region of southeastern Washington that was primarily native grasssland, but has largely been converted to intensive agriculture. Much of this effort is through the Conservation Reserve Program (CRP) to help reduce soil erosion; wildlife damage under such a scenario can be anticipated (Hughes and Gipson 1996). Most studies of porcupine use of woody materials have been conducted on commercial forestland. Hendricks and Allard (1988) studied porcupines in prairies of eastern Montana, but there were no conifer species present. Re-establishing conifers can be especially difficult in the interior Pacific Northwest because of low precipitation levels, vegetative competition, and animal damage.

The authors report levels of porcupine damage to regenerating ponderosa pine stands in the Palouse Region of southeastern Washington and the results of preliminary repellent trials with captive porcupines at Washington State University (WSU). Reference to trade names does not imply U.S. government endorsement of commercial products or exclusion of a similar product with equal or better effectiveness.

METHODS

Damage Survey

The authors surveyed porcupine damage to a 115 ha natural stand of ponderosa pine at Smoot Hill, Whitman County, about 12 km northwest of Pullman, Washington in December 1997. Stand elevation was 920 m, had a northeast aspect, and received about 40 cm of annual precipitation. Trees were rare except along major riparian zones and on some north-facing slopes. The most common plant association was *Festuca idahoensis*/*Symphoricarpos albus* (Franklin and Dyrness 1973). The dominant trees in the stand were about 100 years old and natural regeneration occurred within and around the periphery of the stand. The authors walked a transect along the major axis of the stand and established a 0.047 ha circular plot when a damaged tree was encountered. At each of 10 plots the diameter-at-breast-height (dbh) of each tree was measured and it was noted whether the tree had been damaged. For damaged trees, it was estimated the height of the tree and height(s) at which bark damage had occurred. It was also noted if the tree was alive or dead and whether the bole was completely girdled or merely had patches of bark removed. The tree density (stems/ha) of each plot was also determined.

The authors were also able to survey porcupine damage to four-year-old, planted ponderosa pine seedlings on a CRP project site in Whitman County, Washington. The focus of that study was to test methods to reduce vegetative competition and increase soil moisture availability to planted seedlings of various woody species; details and results of that study were reported in Sanders (1998). Here, the authors report only the observed levels of porcupine damage.

Repellent Pen Trials

Wild-captured porcupines, maintained individually in three 13x4 m outdoor pens at WSU, were used for repellent trials. Daily maintenance included water *ad libitum*, an apple, and pelleted rat chow. Straw for bedding was placed in wooden huts; periodically, pine branches for gnawing were added to each pen. An upright wooden post was placed in the front and rear of each pen with several upward angled holes drilled in each from an upward angle so that fresh-cut pine branches could be inserted for periodic feeding material or for treated branches during repellent trials. On trial days, food was withheld and two pine branches were placed on each of the front and rear posts. One post was randomly assigned branches with no treatment (control); the other post received branches that had been treated with a test repellent. The materials tested, with percent active ingredient, were: bobcat urine (diluted 1:2, urine:tapwater); encapsulated predator odor (EPO), (10 mg mixture of semiochemicals 3-Propyl-1, 2-dithiolane and 2-Propylthietane encapsulated in a clay matrix within a 7 cm plastic tube open at both ends); Deer-Away® (powder, 36% putrid egg solids); Hot Sauce® (liquid, diluted to 0.25% capsaicin); spearmint (liquid, 17% spearmint oil); Repel® (granular, 20% paradichlorobenzene); Chacon Liquid Animal Repellent® (liquid, 21% thiram); Sudbury Chaperone® (liquid, 7% thiram); Ro-pel® (liquid, 0.065% denatonium saccharide); Tree Guard® (liquid, 0.2% denatonium benzoate); and Plant Pro-Tec® (clip-on capsule, 10% garlic oil). Materials in a liquid formulation were sprayed on the branches; powdered materials were sprinkled on branches that had been misted with tap water; and capsules were simply clipped or wired to branches. Branches were placed in pens immediately after treatment. Porcupines were left undisturbed for 24 hours, after which the branches were examined for one of the following damage levels: no damage, slight damage (a few small bites taken from needles or bark, or pulled from the post but not fed upon), or heavy damage (most bark and needles removed with branches usually gnawed into numerous small pieces). All materials were removed and the animals returned to normal maintenance for at least two days before another trial was begun.

RESULTS AND DISCUSSION

Damage Surveys

Twenty-two percent (50 of 225) of the ponderosa pine trees examined had been damaged by porcupines (Table 1). Damage within the 10 plots ranged from 9.4 to 40.0% of the trees. The average dbh of damaged trees (20.9 cm, S.D.=8.7, range=7.6 to 45.7) was greater than that of undamaged trees (18.5 cm, S.D.=8.1, range=6.4 to 45.7). The difference, however, was only moderately significant (P=0.065). Several researchers have reported that damaged trees tended to be the largest trees in the stand (Table 1). While the damaged trees in the authors' survey were larger than average, damage occurred in trees of a wide array of size classes. The largest trees (>36 cm dbh) were rarely damaged; only 1 of 50 damaged trees was >36 cm dbh. The height of damaged trees averaged 9.9 m (S.D.=3.1 m), ranging from 4.6 to 16.8 m. Most damage was in the mid- to upper boles of trees at an average height of 4.7 m (S.D.=2.6 m, range=1.2 to 12.2 m). The type and amount of damage found was similar to that reported in other studies (Table 1). Most damaged trees (88%) had their boles completely girdled versus having only patches of bark removed. In contrast, Sullivan et al. (1986) reported that only 31% of all damaged trees, but 56% of damaged trees over 27 cm dbh, were girdled. The authors also found that almost half (42%) of the damaged trees were damaged in more than one spot on the bole. There was no correlation ($r^2=0.012$) between tree density (range=215 to 924 trees/ha) and percentage of damaged trees. Tenneson and Oring (1985) also found no relation between amounts of damage and tree density, although it has been speculated that more damage occurs in stands with lower tree density (Dodge and Borrecco 1992). All of the pole-sized damaged trees were alive (0% mortality), having had a lateral branch invariably assuming dominance in the case of larger trees. Roze (1989) reported low tree mortality rates in New England because few porcupine damaged trees (4%) were girdled at the base. The authors found no trees on their plots that had been girdled at the base. Typically, basal feeding becomes rare as the bark thickens and nutrients are concentrated farther up the bole (Dodge and Borrecco 1992; Sullivan et al. 1986). Concern has been expressed, however, that even with damage only occurring in the upper bole and not causing tree mortality, the quantity and quality of merchantable wood can be reduced and the likelihood of disease or insect infestation increased (Dodge and Borrecco 1992; Evans 1987; Hooven 1971; Schemnitz 1994).

Relatively few seedlings (about 20/ha) were observed in the understory of the Smoot Hill pine stand. A combination of reasons could account for low levels of natural regeneration: drought, vegetative competition, feeding by a variety of animal species, and antler rubbing by deer (*Odocoileus virginianus*). The authors suspect that porcupines could be responsible for a substantial portion of seedling mortality even though no quantification of seedling damage levels could be found in the published literature. Evans (1987) noted that substantial damage to three-year-old poderosa pine plantations can occur and Hooven (1971) reported that few seedlings or saplings survive once attacked by porcupines. Tenneson and Oring (1985) noted poor regeneration of white pine (*Pinus strobus*) in Minnesota, but did not attribute it to porcupines. The authors noted fresh porcupine damage on 6% (10 of 175) of ponderosa pine seedlings surviving four years after planting on a CRP site in Whitman County. Only 56% of the original 312 seedlings were still alive at that site after four years, but the authors could not determine the portion of overall seedling mortality that was attributable to porcupine feeding because many of the seedlings were missing or had been dead too long to ascertain the cause of death. Nonetheless, the data suggest that porcupines can be an impediment to seedling establishment, especially because porcupine damage is usually chronic in an area (Evans 1987). Sanders (1988) reported that voles (*Microtus* spp.) were the most serious threat to woody vegetation establishment on CRP lands in southeastern Washington.

Repellent Pen Trials

Many (8 of 11) of the materials tested gave promising results in the preliminary pen trials (Table 2). A variety of predator-associated odors (based on urines, semiochemicals, or other sulfur-based, animal-generated

Table 1. Percentage and size class (dbh in cm) of conifer trees damaged by porcupines reported in this and other studies in North America.

Location	Stand Type	Percent Damaged; Size Class	Reference
Washington	ponderosa pine (*Pinus ponderosa*) mature stand	22%, 12 to 30 cm mid- to upper boles	This study
Wisconsin	eastern hemlock (*Tsuga canadensis*) pole-sized stand	30%; 25 to 36 cm	Krefting et al. 1962
Minnesota	scotch pine (*Pinus sylvestris*) small pole-sized	12%; 10 cm largest trees	Rudolf 1949
Minnesota	white pine (*Pinus strobus*) mature stand	42-66%; 30 to 52 cm largest trees	Tenneson and Oring 1985
South Dakota	ponderosa pine pole-sized stand	10%; 15 to 20 cm largest trees, upper boles	Van Deusen and Myers 1962
Idaho	ponderosa pine poles-sized stand	15%; 20 to 25 cm largest trees	Curtis and Wilson 1953
Alberta	Douglas fir (*Pseudotsuga menziesii*) and limber pine (*Pinus flexilis*) pole-sized stand	22-37%; 17 to 26 cm largest trees, upper boles	Harder 1979
British Colombia	western hemlock (*Tsuga heterophylla*) large pole-sized	53%; 28 to 32 cm largest trees, mid- and upper boles	Sullivan et al. 1986

Table 2. Percentage of treated and untreated pine branches heavily damaged by porcupines 24 hours after branch placement in outdoor pens, southeastern Washington, 1997.

	Percent Branches Heavily Damaged	
Treatment	Treated (n=6)	Untreated (n=6)
Bobcat urine	0	100
Semiochemicals (see methods section)	0	33
Putrid egg solids (36%)	0	100
Capsaicin (0.25%)	0	100
Spearmint oil (17%)	0	100
Paradicholorobenzene (20%)	0	100
Thiram (21%)	0	67
Denatonium benzoate (0.2%)	17	67
Denatonium saccharide (0.065%)	67	67
Thiram (7%)	100	100
Garlic oil (10%)	100	100

materials) appeared promising. It may be significant that only 33% of the control (untreated) pine branches in the semiochemicals trial were heavily damaged (Table 2); perhaps the strong predator odor hindered overall feeding by porcupines. Only garlic tabs, 7% thiram, and 0.065% denatonium saccharide did not deter branch feeding for the 24 hour test period. Although no repellents are currently registered to deter porcupine damage, Schemnitz (1994) noted that thiram and wood preservatives may provide some protection. The authors note, however, that some wood preservatives have potential adverse effects to people, animals, or the environment. It is also important to avoid materials that contain salt or certain resins because these may stimulate feeding by porcupines which have a strong attraction to salt (Roze 1989; Schemnitz 1994).

FUTURE DIRECTIONS

The authors believe that the promising preliminary results warrant field trials with several of the materials. These would provide data on the efficacy and duration of repellency under the natural conditions that porcupines experience during winter, the period of most conifer feeding (Dodge and Borrecco 1992; Roze 1989). Weather conditions, snow depth, and forage alternatives—or the lack thereof—could greatly influence results. Conversely, additional pen trials could be conducted to stabilize formulations to increase the period of effectiveness before field trials. Perhaps a band of an appropriate repellent applied around the bole of the tree a few feet above the ground would deter climbing by porcupines. The cost of large-scale repellent application needs to be evaluated; presumably, only vulnerable tree species and size classes would be treated.

Physical barriers of various types could also be tried to restrict tree climbing by procupines. Metal flashing and wire mesh have been suggested by Schemnitz (1994), but the authors have found no published documentation of efficacy or cost-effectiveness. It is possible that expandable bands of barrier material such as bird-repelling "porcupine wires" used on building ledges may deter tree climbing by porcupines while not hindering tree growth. These approaches, however, may prove too costly or labor intensive.

Silvicultural methods might, in theory, be altered to reduce conifer damage by porcupines (Schemnitz 1994; Sullivan et al. 1986). In many cases, however, current silvicultural practices encourage higher densities of porcupines and more damage to conifers (Dodge and Borrecco 1992). Nonetheless, the influence of tree species selection for planting, thinning densities and species selection, tree harvest method, size of harvest area, brush and potential den site removal, tree pruning, stand juxtaposition with adjacent habitats, and other silvicultural practices should be investigated (Dodge and Borrecco 1992).

The authors are involved in porcupine nutrition trials with captive animals at WSU. These trials, being conducted by Dr. Lisa Shipley and graduate student Laura Felicetti, will help better understand not only the nutritional requirements and food passage rates of porcupines, but also their sensitivity to secondary plant compounds such as tannins and terpenes. This knowledge may assist foresters in selecting tree species or genetic varieties that are less susceptible to damage by porcupines (Linhart et al. 1989).

This and other studies have documented substantial cumulative damage to conifers by porcupines in various locations of North America. Attempts to establish conifer stands in the interior Pacific Northwest will continue to be problematic and risky unless effective and affordable solutions to porcupine damage can be developed.

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SURVEILLANCE FOR SIN NOMBRE VIRUS AND HANTAVIRUS PULMONARY SYNDROME IN CALIFORNIA, 1993 TO 1997

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ABSTRACT: Hantavirus Pulmonary Syndrome (HPS), a severe and frequently fatal respiratory disease, was first recognized in 1993 during an outbreak of acute illness in the Four Corners area of the southwestern United States. The etiologic agent, Sin Nombre virus (SNV), was identified as a previously unrecognized member of the Hantavirus genus transmitted by rodents, especially members of the genus *Peromyscus*, which shed SNV in urine and feces. Since 1993, 16 California residents have been diagnosed with HPS, four of these were identified retrospectively with onset prior to 1993. The median age of case-patients was 42 years, 10 were male, and eight died. Sites of likely exposure for these cases tended to cluster in the eastern Sierra Nevada range. Serologic surveillance of rodents has been conducted prospectively in California since 1993 and retrospectively for specimens collected back to 1975. To date, serologic evidence of infection with SNV has been recognized in 473 (6.6%) of 7,191 rodents from 18 genera, and in 426 (9.6%) of 4,489 *Peromyscus* spp. At least one seroreactive *Peromyscus* sp. specimen has been identified in 40 of 46 counties surveyed.

KEY WORDS: hantavirus, hantavirus pulmonary syndrome, Sin Nombre virus, deermice, *Peromyscus*

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INTRODUCTION

Hantavirus pulmonary syndrome (HPS) was first recognized in 1993 when an outbreak of an acute illness of unknown etiology occurred among residents of the Four Corners area in the southwestern United States (CDC 1994). The illness was characterized by a prodrome of fever and flu-like symptoms which rapidly progressed to respiratory distress and was frequently fatal. The etiologic agent was identified as a previously unrecognized member of the Hantavirus genus that was given the provisional name of Sin Nombre virus (SNV). Rodents, especially members of the genus *Peromyscus*, were identified as the principal reservoir of the virus, which they shed in urine and feces.

Since 1993, the California Department of Health Services, in cooperation with local health agencies and vector control programs, has conducted surveillance for hantavirus in human and non-human mammals in California. This report summarizes results of this surveillance from 1993 to 1997.

METHODS

HPS Cases

Passive surveillance for HPS cases is conducted through the Division of Communicable Disease Control of the California Department of Health Services (DHS). Serologic testing of suspect HPS patients is provided through the Viral and Rickettsial Diseases Laboratory (VRDL), DHS. A suspect HPS case is defined as a previously healthy patient experiencing a febrile illness (i.e., temperature greater than 101° F) characterized by bilateral diffuse interstitial edema that may radiographically resemble adult respiratory distresss syndrome, with respiratory compromise requiring supplemental oxygen, developing within 72 hours of hospitalization (CDC 1998). California health care providers desiring serologic testing of a suspect HPS case are requested to submit 5 to 10 ml of acute whole blood to the VRDL. An immunofluorescent antibody procedure with SNV antigen is used for testing for hantavirus antibody activity in serum specimens. An attempt is made to obtain a convalescent blood sample on all patients for whom the acute specimen was reactive. For fatal cases, specimens of lung and kidney tissue are requested.

Information on the suspect patient's acute illness is collected in the case history form which accompanies the serologic specimen and, in the event of a confirmed case, through detailed abstraction of the complete medical record. Information on the patient's work-related and recreational activities, place of residence, and recent travel are collected from the patient or a proxy to assist in determining the likely circumstances of exposure. On-site investigations of the patient's residence and other likely exposure locales are conducted by public health biologists and environmental health specialists from the state and local health departments.

Rodent Surveillance

As part of the environmental follow-up conducted on all confirmed HPS cases in California, attempts are made to collect blood from rodents at each potential exposure site. Procedures and total trap-nights vary according to the suspected circumstances of the patient's exposure (e.g., occupational versus peridomestic) and the interval between confirmation of the case and initiation of the environmental follow-up. Blood samples are obtained from collected rodents by intracardiac puncture using a 1 ml. tuberculin hypodermic needle. Blood samples are chilled and shipped on ice to VRDL for processing. Serologic testing is conducted as previously described (Jay et al. 1997). Specimens with antibody activity detectable at a dilution of 1:64 or greater are considered reactive.

In addition to responsive surveillance, since 1993 DHS and other agencies have routinely collected serum specimens for hantavirus evaluation from rodents throughout California. Also, selected archived specimens, including sera, tissues, and whole carcasses, from rodents collected in California back to 1975 have been tested for evidence of hantavirus infection.

RESULTS AND DISCUSSION

HPS cases

Since 1993, 16 California residents have been diagnosed with HPS (Table 1). Four of these were identified retrospectively, with onset of illness having occurred in 1980, 1984, and two in 1992. Eight cases had a fatal outcome. The median age of case-patients was 42 years (range, 22 to 56) and 10 were male. Case-patients were residents of 11 counties—Alameda, Contra Costa, Inyo (2), Kern, Modoc, Mono (4), Nevada (2), Plumas, Santa Barbara, San Bernardino, and San Francisco (Figure 1). Probable sites of exposure included the counties of Inyo (2), Modoc, Mono (4 or 5), Nevada (2), Placer, Plumas, and Santa Barbara, and the states of New Mexico (2) and Washington. Probable exposure site could not be reliably determined for one case. The circumstances of exposure were peridomestic for seven cases, occupational for four, recreational for three, and unknown for two. Detailed clinical and epidemiologic features of select California HPS cases have been previously described (Flood et al. 1995; Schwarcz et al. 1996; Shefer et al. 1994; Jay et al. 1996).

Rodent Surveillance

Testing for hantavirus seroreactivity in California mammals has been performed on specimens from 7,295 animals, representing 51 species of 27 genera. Among the 18 genera of rodents evaluated, evidence of hantavirus seroreactivity has been identified in seven (Table 2). Six species of the genus *Peromyscus* have demonstrated the most consistent seroreactivity; 426 (9.6%) of 4,489 *Peromyscus* spp. tested had detectable antibody to SNV (Table 3). At least one seroreactive *Peromyscus* specimen has been identified in 40 of 46 counties sampled (Figure 1).

Reithrodontomys megalotis and *Microtus californicus* specimens have demonstrated evidence of infection with Sin Nombre-like hantaviruses (El Moro Canyon and Isla Vista, respectively), but these strain variations have not been shown to be pathogenic to humans. Seroreactivity has been occasionally identified in *Neotoma* sp., *Perognathus* sp., and *Spermophilus* sp. rodents in California and elsewhere; however, it is believed that these species are incidentally infected with SNV and are not competent reservoirs or vectors. There is no serologic evidence to date of SNV infection in domestic rodent species (i.e., *Mus* spp., *Rattus* spp.), lagomorphs, or wild and domestic carnivores.

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Table 1. Hantavirus pulmonary syndrome cases diagnosed in California residents, 1980 to 1997.

Onset	Age	Sex	County of Residence	Outcome	Likely Exposure Location	Exposure Circumstances/ Follow-up Investigation
Feb 1980	22	M	San Francisco	Died	New Mexico	Rodent infestation at adobe home in NM
Feb 1984	34	F	Inyo	Died	Deep Springs, Inyo Co.	Heavy rodent infestation at residence
Sep 1992	29	M	Santa Barbara	Died	Solvang, Santa Barbara Co.	Trapped and handled rodents prior to illness
Aug 1992	49	F	Alameda	Died	Mono Co. or WA State	Backpacked in Mono Co. and WA 2 to 4 weeks prior to illness
Jul 1993	27	F	Mono	Died	Mammoth Lakes, Mono Co.	Two strains of SNV isolated from rodents near patient's worksite
Mar 1994	42	F	San Bernardino	Survived	New Mexico	SNV(+) rodents from NM residence; no SNV(+) rodents from CA residence
May 1994	42	M	Kern	Died	Undetermined	Cleaned out rodent-infested building prior to onset; no SNV(+) rodents at residence or worksite
Sep 1994	56	M	Mono	Survived	Lee Vining, Mono Co.	SNV(+) rodents at patient's residence and worksite (7 of 42)
Feb 1995	42	F	Mono	Survived	Walker, Mono Co.	Swept out garage with rodent droppings; SNV(+) rodents at patient's residence (3 of 22)
Mar 1995	47	M	Nevada	Survived	Nevada Co.	SNV(+) rodents at patient's residence (11 of 13) and worksite (6 of 19)
Jun 1995	45	M	Mono	Died	Crowley Lake, Mono Co.	Cleaned rodent-infested home; SNV(+) rodents at residence (6 of 11)
Aug 1995	55	M	Contra Costa	Died	Cisco Grove, Placer Co.	Camped in Sierra Nevada; SNV isolated from Placer Co. rodent matched patient isolate
Sep 1995	32	F	Plumas	Survived	Graeagle, Plumas Co.	SNV isolated from 1 of 21 Plumas Co. rodents matched patient isolate
Jul 1996	49	M	Modoc	Survived	Alturas, Modoc Co.	SNV(+) rodents at residence (1 of 3) and other nearby sites (9 of 62)
Jul 1997	43	M	Nevada	Survived	Tahoe-Donner, Nevada Co.	Hiked in Tahoe-Donner; SNV(+) rodents at hiking trails (5 of 16) and areas near home (22 of 71)
Oct 1997	38	M	Inyo	Survived	Bishop, Inyo Co.	Noted rodent excreta at worksites; SNV(+) rodents at worksite (2 of 23)

Table 2. Serologic results of surveillance for hantavirus in rodents collected in California, 1975 to 1997.

Species	Number Collected	Number Reactive (%)
Ammospermophilus leucurus	4	0
Chaetodipus californicus	17	0
Clethrionomys spp.	1	0
Dipodomys spp.	40	1 (2.5%)
Glaucomys sabrinus	1	0
Microtus spp.[1]	41	7 (17.1%)
Mus musculus	119	0
Neotoma spp.	534	6 (1.1%)
Onychomys torridus	1	0
Perognathus spp.	72	2 (2.8%)
Peromyscus boylii	196	3 (1.5%)
P. californicus	328	10 (3.0%)
P. crinitus	44	3 (6.8%)
P. eremicus	179	4 (2.2%)
P. maniculatus	3,349	390 (11.6%)
P. truei	348	15 (4.3%)
Peromyscus sp.	45	1 (2.2%)
Rattus spp.	146	0
Reithrodontomys megalotis[2]	205	30 (14.6%)
Sciurus griseus	1	0
Sigmodon hispidus	14	0
Spermophilus spp.	1,228	1 (0.1%)
Tamias spp.	270	0
Tamiasciurus douglasii	8	0

[1]Isla Vista virus

[2]El Moro Canyon virus

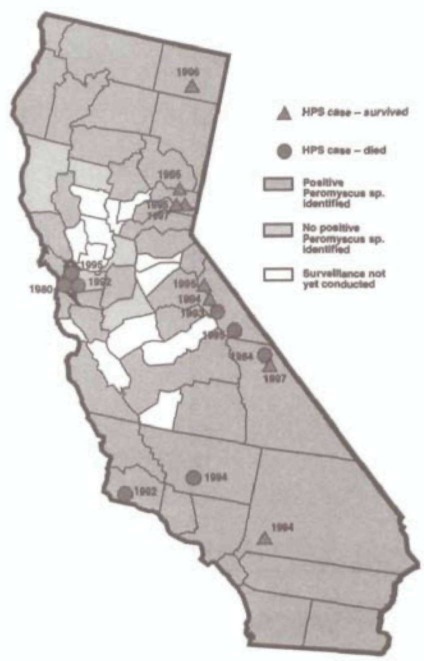

Figure 1. Distribution of hantavirus pulmonary syndrome (HPS) human cases (by county of residence) and *Peromyscus* spp. seroreactive to Sin Nombre virus in California, 1975 to 1997.

Table 3. Serologic results of surveillance for Sin Nombre virus among *Peromyscus* spp. in California, 1975 to 1997.

County[1]	Number Collected	Number Reactive (%)
Alameda	6	1 (16.7%)
Alpine	55	11 (20.0%)
Butte	145	15 (10.3%)
Contra Costa	36	0
Del Norte	54	1 (1.9%)
El Dorado	51	6 (11.8%)
Fresno	249	34 (13.7%)
Glenn	8	0
Humboldt	61	5 (8.2%)
Imperial	18	3 (16.7%)
Inyo	37	3 (8.1%)
Kern	84	7 (8.3%)
Lake	49	4 (8.2%)
Lassen	32	3 (9.4%)
Los Angeles	326	15 (4.6%)
Marin	92	3 (3.3%)
Mendocino	19	0
Merced	78	8 (10.3%)
Modoc	77	11 (14.3%)
Mono	176	34 (19.3%)
Monterey	130	6 (4.6%)
Mariposa	58	7 (12.1%)
Nevada	139	52 (37.4%)
Orange	268	10 (3.7%)
Placer	29	2 (6.9%)
Plumas	67	14 (20.9%)
Riverside	217	2 (0.9%)
Sacramento	36	0
San Bernardino	89	3 (3.4%)
San Diego	447	15 (3.4%)
San Francisco	30	0
San Mateo	81	2 (2.5%)
Santa Barbara	352	89 (25.3%)
Santa Clara	103	1 (1.0%)
Shasta	37	4 (10.8%)
Sierra	48	9 (18.8%)
Siskiyou	122	13 (10.7%)
San Joaquin	11	1 (9.1%)
San Luis Obispo	94	6 (6.4%)
Sonoma	143	3 (2.1%)
Stanislaus	15	0
Tehama	35	5 (14.3%)
Trinity	24	8 (33.3%)
Tulare	20	2 (10.0%)
Tuolumne	32	1 (3.1%)
Ventura	237	11 (4.6%)
Total	4,517	430 (9.5%)

[1]Counties in which surveillance for hantavirus in rodents has yet to be conducted are not listed.

WILL CONTINUED MONITORING OF BEAVER DAMAGED RESOURCES MINIMIZE FUTURE DAMAGE?

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ABSTRACT: The purpose of this study was to determine if continued monitoring and removal of beavers (*Castor canadensis*) from previously controlled beaver damage sites resulted in less additional damage than not monitoring such sites. Beavers were removed from 34 sites in nine southeast Texas counties from August 1996 through March 1997. Sixteen sites subsequently were monitored monthly and, if beavers had reinvaded, they were removed and the additional damage value was recorded. The remaining 18 sites were not monitored monthly, but they were visited for a final survey at the end of the study. The value of additional damage was recorded at that time. Damage following reinvasion occurred more often when sites were not monitored (5 of 7 sites, compared to only 2 of 7 reinvaded, monitored sites). In addition, when damage occurred at reinvaded sites, monetary value appeared to be greater without monitoring (average $940, n=5) than with monitoring (average $125, n=2). The larger average damage values for reinvaded unmonitored sites compared to reinvaded monitored sites would be important to landowners when deciding if property should be monitored. Factors that made some sites susceptible to reinvasion were also evaluated. Significantly more beavers were taken initially, per site, in the reinvaded sites compared to all other sites. This implies that better habitat and higher beaver density were the most important factors in determining a site's susceptibility to reinvasion.

KEY WORDS: beaver, damage, monitoring, primary removal, secondary removal, reinvasion

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INTRODUCTION

A growing beaver (*Castor canadensis*) population and subsequent resource damage have become a problem in much of the southeastern United States, including Texas (Woodward 1983; Ramsey and Wade 1986). Beaver numbers are high, especially in the eastern third of Texas, and their range is expanding (Ramsey and Wade 1986). According to Ramsey and Wade (1986), damage is severe in eastern parts of Texas, and beaver control is legal year round.

Damage values associated with beaver activities have been estimated for parts of the U.S. and Texas. Woodward (1983) reported that the estimated value of damage (including value of finished wood products) on 400,000 hectares in the southeastern U.S. exceeded four billion dollars during the last 40 years. The Texas Agricultural Extension Service estimated that beavers caused $34 million in damage during 1994 in a 42-county area in the eastern third of the state (Douglas 1995; Upshaw 1995). The U.S. Department of Agriculture - Wildlife Services Program in Texas reported $2.4 million in beaver damage in its State Damage Summary for beavers for the period October 1996 through September 1997 (Anonymous 1996).

When Texas Wildlife Services Program personnel remove beavers from damage sites, landowners are urged to monitor their property to minimize additional damage by reinvading beavers. Many times landowners do not monitor their property after beavers are removed. Population dynamics help explain why monitoring is important. As numbers of beavers within colonies increase, there is more pressure on younger beavers to disperse. They may travel only 2 to 3 km but usually travel up to 8 to 16 km and have been known to travel as much as 161 km in search of new homes (Jackson 1996). Also, their dispersal rate has been reported to be about 0.7 to 1 km per night (Weaver 1986). Beavers can travel great distances in a short period of time. Due to this fact and the fact that beaver numbers are large and continue to increase in Texas, property can be reinvaded quickly. Beavers have been known to quickly reinvade previously controlled sites.

This project attempted to answer the following questions: Can landowners minimize additional damage from reinvading beavers by periodically monitoring sites after initial removal of beavers? Conversely, is the damage going to be the same whether resources are monitored or not? If damage can be minimized by continued monitoring, then how great is the difference in the amount of additional damage between monitored and "neglected" (unmonitored) sites? In addition, what factors made some sites more susceptible to reinvasion than others?

STUDY AREA

The sites were located in nine southeast Texas counties. Total area for the nine counties is 2,003,573 ha. The Brazos and Navasota Rivers are the major drainage systems for the eight contiguous counties in this study area and are probably the primary sources of beavers.

METHODS

Beaver damage surveys and initial removal of beavers from damage sites (primary removal) began in August 1996. Removal of reinvading beavers (secondary removal) continued until March 1997. Removal methods included: body grip traps, leghold traps, neck snares and shooting. Thirty-four sites were included in this study. Each site contained only one family group of beavers and all sites were within the parameters identified by Buech (1985) for one beaver colony.

The 34 sites were divided into two categories, monitored and unmonitored. The sites were alternately designated monitored or unmonitored as requests for assistance were received. Sixteen sites were selected for monthly monitoring, and the remaining 18 sites were not monitored (unmonitored). After primary removal, monitored sites were evaluated monthly until March 1997. If beavers had returned to a site, they were removed. Additional damage since the time of primary removal was recorded for each site. For unmonitored sites, a final survey was completed some time between January 12, 1997 and March 15, 1997; no beavers were removed from these sites after primary removal. In the final survey of unmonitored sites, if reinvasion had occurred, additional damage was assessed. A checklist was used to assess resource damage and to record numbers and ages of beavers taken. Beaver age was estimated based on body weight.

Differences in damage estimates between monitored and unmonitored groups were evaluated using a standard t-test (significance was determined in all t-tests using $P \leq 0.05$.) The non-reinvaded sites in both groups were given \$0 values. The original hypothesis was that additional damage for unmonitored sites would be larger.

Delorme Map Expert® software was used to determine distance to a permanent water source (river, major tributary, etc.) for each site (Table 1). These distances represent waterway distances, when waterways could easily be followed on the maps. The difference in distances to a permanent water source between all reinvaded and all non-reinvaded sites was tested for significance with a standard t-test. The original hypothesis for the test was that the distance was smaller for reinvaded sites. Exposure days were also calculated for each site (Tables 2 and 3). These were the number of days a site was susceptible to reinvading beavers. The total exposure days for sites were from the last day of primary removal to the last visit. A standard t-test was used to determine if there was a significant difference in exposure days between monitored and unmonitored groups. Also, the difference between exposure days for reinvaded unmonitored sites and non-reinvaded unmonitored sites was tested for significance with the standard t-test. The original hypothesis was that the number of exposure days would be greater for reinvaded unmonitored sites. Correlation between exposure days and amount of additional damage for reinvaded, unmonitored sites was evaluated with a linear regression analysis.

Difference in numbers of beavers taken in primary removal between reinvaded sites and non-reinvaded sites was tested for significance with the standard t-test. The original hypothesis was that reinvaded sites had more beavers taken in primary removal.

RESULTS

The total number of beavers taken in primary removal was 121; 52% were adults, 16% were juveniles, and 32% were of unknown age (Table 2). The average number of beavers taken per site was 4 ± 2. Numbers of beavers taken at sites ranged from 1 to 12. The total initial damage estimate before primary removal began was \$52,865. The average for each site was \$1,555 ± \$1,523.

Seven of 16 monitored sites (44%) were reinvaded by beavers (Table 3). Two of the seven sites were reinvaded within two months and the other five were reinvaded within one month. The total number of reinvading beavers taken in secondary removal was 22; 68% were adults, 14% were juveniles, and 18% were of unknown age. The average number of beavers taken in reinvaded sites was 3 ± 1. Six of seven reinvaded sites were reinvaded only once; one site was reinvaded three times. The total additional damage estimate for monitored sites was \$250 (Table 4). The average damage estimate for these sites was \$36 ± \$55. Seven of 18 unmonitored sites (39%) were reinvaded (Table 5). The total additional damage estimate was \$4,700. The average damage estimate for these sites was \$671 ± \$947.

Seven monitored and seven unmonitored sites were reinvaded by beavers (14 of 34 sites). Damage following reinvasion occurred more often when sites were not monitored (5 of 7 sites compared to only 2 of 7 reinvaded monitored sites). When damage occurred at reinvaded sites, monetary value appeared to be greater without monitoring (average \$940, $n=5$) than with monitoring (average \$125, $n=2$). However, a t-test using $P \leq 0.05$ to determine significance indicated that there was no significant difference in damage values between monitored and unmonitored sites ($P=0.08$).

The average distance to a permanent water source for all sites was 2.4 ± 2.4 km (Table 1). The average distance for all reinvaded sites was 1.9 ± 2.7 km. The average distance for all non-reinvaded sites was 2.6 ± 2.2 km. No significant differences were found in distances to permanent water sources between reinvaded sites and non-reinvaded sites ($P=0.24$).

Linear regression analysis showed little correlation between number of exposure days and amount of additional damage for reinvaded unmonitored sites. The correlation coefficient ($r=-0.3$) was not significant.

Average number of exposure days for monitored sites was 104 ± 42. The average number of exposure days for unmonitored sites was 95 ± 40. There was no significant difference in exposure days between the two groups ($P=0.53$). The average number of exposure days for reinvaded unmonitored sites was 73 ± 26 days. The average number of exposure days for non-reinvaded unmonitored sites was 109 ± 44 days. The original hypothesis was rejected, as non-reinvaded rather than reinvaded unmonitored sites were found to have a significantly larger number of exposure days ($P=0.02$).

A significant difference was seen in the number of beavers taken in primary removal between reinvaded sites and non-reinvaded sites ($P=.003$). Seventy beavers were initially taken in the 14 reinvaded sites (Avg.=5 ± 3 beavers/site). Fifty-one were taken from the other 20 sites (Avg.=3 ± 1 beavers/site).

Table 1. Beaver damage site information.

Site Name	County	Area (ha)	Monitored monthly (yes/no)	Distance from major stream/river (km)	Name
Bower's Lake	Burleson	12	yes	0.2	Davidson Cr.
Camp Creek Lk.	Robertson	304	yes	4.8	Camp Cr.
CCWD #19	Fayette	13	yes	0.3	Spencer Pool Cr.
CCWD #22	Fayette	11	yes	1.3	Spencer Pool Cr.
CCWD #26	Fayette	6	yes	0.5	Cummins Cr.
Chick Ln. Stables	Brazos	1	yes	0.6	Turkey Cr.
CIC Agency, Inc.	Brazos	1	yes	5.6	Peach Cr.
Clay Place	Washington	2	yes	0.8	Yegua Cr.
TMPA DP-1	Grimes	18	yes	2.7	Gibbons Cr.
Fletcher/Koening	Washington	2	yes	3.2	Independence Cr.
McCully	Brazos	1	yes	0.0	Bee Cr.
McDaniel Farm	Fayette	1	yes	2.7	Clear Cr.
Moore Ranch	Brazos	18	yes	2.9	Brazos River
Nicholson Club	Polk	1	yes	0.2	Piney Cr.
Schumacher	Washington	1	yes	5.1	Yegua River
TAMU Annex	Brazos	1	yes	1.8	Thompson's Cr.
TMPA 6A	Grimes	15	no	1.6	Gibbons Cr.
TMPA 7A	Grimes	9	no	1.3	Gibbons Cr.
Bourn/Goodwin	Brazos	1	no	1.0	Little Cedar Cr.
Breaux	Milam	1	no	1.1	Sixmile Cr.
Ferguson	Burleson	1	no	4.5	Cedar Cr.
Hill Creek Ranch	Burleson	5	no	4.5	E. Yegua Cr.
Howard Smith	Leon	2	no	0.0	E. Caney Cr.
Kellas	Leon	1	no	4.2	Lwr. Keechi Cr.
Knight Ranch Rd.	Leon	1	no	1.4	Malochomy Cr.
Kristoff	Burleson	2	no	1.9	Davidson Cr.
Marge Nelson	Leon	6	no	10.1	Navasota River
Oakwood Sewer	Leon	1	no	0.0	E. Caney Cr.
TMPA P12	Grimes	1	no	0.3	Panther Cr.
Prince	Grimes	2	no	4.0	Gibbons Cr. Res.
TMPA SP-10	Grimes	15	no	0.5	Gibbons Cr.
Tract 1080 (VLB)	Burleson	4	no	1.6	E. Yequa Cr.
Pike Tree Farm	Leon	2	no	1.0	Mustang Cr.
Truelock	Leon	1	no	8.7	Brushy Cr.
Total		463			
Average		14		2.4	
Standard deviation		51		2.4	

Table 2. Primary removal results and exposure days.

Site Name	Age Group Adult	Juvenile	Unknown	Total	Initial damage estimate ($)	Exposure Days
Bower's Lake	3	0	0	3	1,000	47
Camp Creek Lake	2	1	0	3	3,000	114
CCWD #19	0	0	5	5	1,500	116
CCWD #22	2	2	0	4	2,000	132
CCWD #26	2	0	0	2	1,000	107
Chick Ln. Stables	1	0	0	1	300	173
CIC Agency, Inc.	0	1	0	1	0	116
Clay Place	1	1	0	2	1,500	79
TMPA DP-1	1	0	3	4	1,154	87
Fletcher/Koening	2	4	0	6	2,925	57
McCully	3	0	0	3	500	186
McDaniel Farm	0	0	2	2	500	111
Moore Ranch	0	0	12	12	4,000	37
Nicholson Club	2	1	0	3	300	52
Schumacher	1	0	0	1	150	154
TAMU Annex	2	0	0	2	150	103
TMPA 6A	4	1	0	5	2,308	39
TMPA 7A	3	0	0	3	1,154	93
Wayne Bourn/Goodwin	2	0	0	2	55	56
Breaux	3	1	0	4	650	86
Ferguson	0	0	1	1	500	183
Hill Creek Ranch	2	2	0	4	1,000	93
Howard Smith	0	0	4	4	300	99
Kellas	2	0	0	2	1,000	40
Knight Ranch Road	2	0	0	2	550	46
Kristoff	4	2	0	6	450	93
Marge Nelson	0	0	7	7	3,000	63
Oakwood Sewer	2	0	0	2	1,400	114
TMPA P12	2	1	0	3	3,462	113
Prince	1	1	0	2	500	184
TMPA SP-10	0	1	5	6	3,462	93
Tract 1080 (VLB)	8	0	0	8	6,600	85
Pike Tree Farm	4	0	0	4	5,000	135
Truelock	2	0	0	2	1,000	99
Total	63	19	39	121	52,865	
Average	2	1	1	4	1,555	
Standard deviation	2	1	3	2	1,523	

Table 3. Secondary removal results for monitored sites.

Site Name	Reinvaded (yes/no)	Adults	Juvenile	Unknown	Total	No. of times removed	Time to reinvasion (months)
Bower's Lake	yes	1	2	0	3	1	1
Camp Creek Lake	no						
CCWD #19	yes	0	0	4	4	1	2
CCWD #22	no						
CCWD #26	no						
Chick Ln. Stables	no						
CIC Agency, Inc.	no						
Clay Place	no						
TMPA DP-1	yes	4	0	0	4	1	2
Fletcher/Koening	no						
McCully	yes	3	1	0	4	3	1
McDaniel Farm	no						
Moore Ranch	yes	0	0	0	0	1	1
Nicholson Club	yes	3	0	0	3	1	1
Schumacher	no						
TAMU Annex	yes	4	0	0	4	1	1
Total		15	3	4	22		
Average		2	0	1	3		1
Standard deviation		2	1	1	1		0.5

Table 4. Amount of additional damage after primary removal on monitored sites.

Site Name	Reinvaded (yes/no)	Additional damage ($)	Type of Damage
Bower's Lake	yes	0	Damage threat, digging in dam
Camp Cr. Lake	no		
CCWD #19	yes	0	Damage threat, digging in dam
CCWD #22	no		
CCWD #26	no		
Chick Ln. Stables	no		
CIC Agency, Inc.	no		
Clay Place	no		
TMPA DP-1	yes	0	Damage threat, draw down pipe
Fletcher/Koenig	no		
McCully	yes	0	Damage threat, draw down pipe
McDaniel Farm	no		
Moore Ranch	yes	0	Damage threat, dammed drainage
Nicholson Club	yes	150	Plugged culvert, damaged road
Schumacher	no		
TAMU Annex	yes	100	Dammed drainage
Total no. reinvaded	7		
Total damage		250	
Avg. dmg. reinvaded		36	
STD for damage		58	

Table 5. Amount of additional damage after primary removal on unmonitored sites.

Site Name	Reinvaded (yes/no)	Additional damage($)	Type of Damage
TMPA 6A	yes	200	Dammed drainage
TMPA 7A	no		
Bourn/Goodwin	no		
Breaux	no		
Hill Creek Ranch	no		
Kristoff	yes	0	Dammed drainage
TMPA P12	no		
Prince	no		
TMPA SP-10	yes	300	Plugged drain
Tract 1080 (VLB)	yes	0	Flooded timber
Ferguson	no		
Marge Nelson	yes	2,900	Timber and roads
Knight Ranch Road	no		
Truelock	no		
Howard Smith	yes	500	Timber
Kellas	yes	800	Timber and roads
Oakwood Sewer	no		
Pike Tree Farm	no		
Total no. reinvaded	7		
Total damage		4,700	
Avg.damage for reinvaded		671	
STD for damage		947	

DISCUSSION

Lack of significant difference in additional damage between monitored and unmonitored sites was most likely due to the high variance in damage values for the unmonitored sites. Less variance in damage values might be achieved in the future by obtaining a larger sample size. Although there was not a significant difference between the two groups, $\underline{P}=.08$ suggests that monitoring may have been important. The difference in damage values between the two groups (average damage for reinvaded unmonitored sites was $671, average damage for reinvaded monitored sites was $36) would be important to landowners. Also, five of seven reinvaded sites in the monitored group had $0 damage compared to only two of seven with $0 damage for the reinvaded sites in the unmonitored group. Monitored sites were left unchecked for only a month at a time, and reinvaded sites in this group with $0 damage were controlled again before beavers had time to cause additional damage. Unmonitored sites, on the other hand, were all left unchecked longer than a month. Beavers had a longer time to cause damage, and they did.

Among unmonitored sites that were reinvaded, there was no significant correlation between number of exposure days and amount of additional damage ($r=-0.3$). Some sites had relatively few exposure days, but, at the same time, had relatively large additional damage values. This was related to variability among sites because properties and resources were different, and resources differed in value.

The evaluation of differences in exposure days between monitored and unmonitored sites was used to determine if biases existed that resulted in the unmonitored group having more exposure days, increasing the likelihood of reinvasion. However, no significant difference was found between the two groups.

The authors' data suggests that additional damage was minimized and sometimes totally prevented by evaluating sites for the presence of beavers and promptly removing new beavers. Further study is needed to determine if damage is significantly different between monitored and unmonitored sites. The results of this project support the concept that landowners will be able to minimize additional damage by regularly monitoring their property and removing reinvading beavers quickly.

The second question addressed in this study was, "What factors made some sites more susceptible to reinvasion than others?" One possible factor could have been shorter distance to permanent water sources for some sites. Assuming beavers were in a permanent water source, dispersers could return to the site more quickly. However, distance to a permanent water source for reinvaded sites was not significantly less than the distance for all the other sites.

A second factor related to reinvasion susceptibility might have been the number of days between surveys for unmonitored sites. Reinvaded, unmonitored sites could have had more exposure days, compared to non-reinvaded unmonitored sites, which would allow more time for reinvasion. However, a t-test showed that in this case, the opposite was true. For the unmonitored group, non-reinvaded sites had significantly more exposure days compared to reinvaded.

A third factor in susceptibility to reinvasion could have been alteration of the site which made it unsuitable for beavers. One site was altered after primary removal, which could have prevented reinvasion. A larger culvert was installed, and the area was drained. Alteration to prevent beaver reinvasion at other sites was either not desired by the landowners, or was too costly.

A final factor could have been differences in quality of habitat for certain areas. Better habitat should support more beavers and possibly hasten reinvasion into a previously controlled site. The importance of this factor was tested, indirectly, by comparing the number of beavers taken in primary removal between reinvaded sites and all other sites, with the assumption that better habitat would support more beavers for a given site or colony. Buech (1985) stated that habitat quality is an important factor in determining family (colony) size. The authors' data support this by showing significantly more beavers taken in primary removal, per site, in the reinvaded sites compared to other sites.

Every site in this study, except Camp Creek Lake, was less than 20 ha, which fit into the home range for one beaver family (Buech 1985). Camp Creek Lake measured 304 ha, but had only one family group of beavers. Some of the sites had more than one beaver lodge, but within each site all lodges were used by the same family of beavers.

If a reinvaded site had relatively better habitat quality, then surrounding habitat may have also been of better quality. Therefore, beaver density in the whole area may have been relatively high. It appears likely that quality beaver habitat recently opened up by removal would be reinvaded sooner in a high beaver density area. Aleksiuk (1968) found a Canadian population of transient two-year old beavers ready to permanently settle in suitable sites when they became available. A high beaver density area would have a higher population of transients, and reinvasion would occur sooner.

Weaver (1986) also discussed the importance of sub-adult (two-year old) beaver dispersal in the overall expansion of beaver populations. He suggested that the reason this particular age class is so important is because of possible delayed dispersal due to unsuitable colonization sites. Delayed dispersal is due to the fact that as beaver densities in an area increase, less sites are available for new colonization, and dispersal by young beavers decreases. Resident beavers may instinctively build more scent mounds as the relative number of dispersers passing through their territories increases. Dispersers may react to the prevalence of scent mounds encountered as they pass through territories. Young beavers may explore surrounding territories but withdraw when they encounter large numbers of fresh scent mounds. Young beavers who delay dispersal and grow larger have a better chance of being successful once they do disperse. They may not disperse until they are two years old or older. Therefore, in high beaver density areas, most beavers that reinvade newly opened territories should be two-year old sub-adults (Weaver 1986).

Adults comprised 68% of the reinvading beavers taken in this project. Non-breeding adults (sub-adults) were not differentiated from breeding adults as long as they were close to the same size. The percentage of adults probably would have been larger if the age of all beavers had been known. Because most reinvading beavers were adults or sub-adults, it could be hypothesized that the sites from which they were taken were high beaver density areas. Delayed dispersal along with better habitat quality can also help explain higher numbers of beavers initially taken per site for reinvaded sites. Additionally, another indication of relatively high beaver densities in the areas of reinvaded sites is that monitored sites were reinvaded so quickly, five sites within one month and the other two sites within two months.

It appears from this study that varying habitat quality and subsequent beaver density are the most important factors in determining a site's susceptibility to reinvasion. However, all damage sites are at risk of reinvasion and monitoring is appropriate at all sites where damage has occurred. Threshold density per unit area, which would cause a site to be reinvaded in a given time period, is unknown and warrants further investigation.

CONCLUSIONS

Reported beaver damage has increased in Texas in recent years. However, many resource managers do not realize how quickly beavers can reinvade sites, and some have experienced extensive beaver damage because of this lack of knowledge. Resource managers have often believed that once beavers were removed from a site, they would be gone forever, or it would take years for other beavers to return. They tend not to sufficiently evaluate their property because they lack knowledge of beaver densities in the area and are not aware of beaver population structure and dynamics.

Beavers will travel great distances in search of a suitable colony site, and resource managers should be informed that when beavers are removed from a site, a favorable site for reinvasion is created. Using continued monitoring of beaver damaged resources as a beaver damage management tool can minimize additional beaver damage.

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ONE HUNDRED YEARS OF POCKET GOPHER TRAPS AND TRAPPING

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ABSTRACT: The pest status of pocket gophers (*Thomomys* spp. and *Geomys* spp.) to agricultural crops and home gardens is well established, as is the fact that trapping in the early history of this country and its western expansion was the predominant method of their control. The former payment of bounties for gopher scalps or tails is thought to have stimulated the development and production of dozens of different kinds and models of gopher traps. In the midwest, prior to the industrial revolution, small size leg-hold traps were used for taking gophers because they were the only traps available. By 1880, traps were being developed and manufactured specifically for gophers, with a dozen or so marketed prior to 1900. The zenith of gopher trap development was from 1900 through the 1930s. Following the end of World War II, the use of poison baits for gopher control significantly replaced the use of traps. Five of the most successful gopher traps, all with a long history of production, are enumerated and the specific history of the Macabee gopher trap is detailed.

KEYWORDS: pocket gophers, gopher control, traps, trapping, trap development, trap history

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GOPHERS AS PESTS

Pocket gophers, of one species or another, can be serious pests, causing damage to a wide range of agricultural crops, to home gardens, to many types of landscaping, and often to forest regeneration efforts (Figure 1). In addition to the crops or other vegetation they destroy, they are also capable of considerable physical damage by gnawing on buried plastic water pipes and underground electrical and communication lines. Their burrows cause substantial losses of irrigation water, especially in flood irrigated crops. Their burrowing activities weaken earthen dams, levees, and dikes, resulting in major and costly breaks.

Figure 1. Botta's pocket gopher (*Thomomys bottae*) causes the most significant damage to California agriculture.

When this country began to expand with the westward movement of settlers to the mid- and far-west, farming endeavors were impacted severely by pocket gophers, as well as other prolific rodents such as ground squirrels and prairie dogs. Especially effected were vegetable crops, orchards, and vineyards. Root crops such as potatoes, sweet potatoes, beets, parsnips, turnips, and carrots are favorite foods of gophers, as are field crops such as alfalfa and clover. Orchard trees such as apples, plums, almonds, peaches, and cherries are killed as a result of the crowns or major roots being completely girdled.

BOUNTIES

When the country was young, so great was the damage caused by pocket gophers that in many regions bounties were placed on the animal's scalp or tail. Benton County, Iowa had a pocket gopher bounty program as early as 1866, when 10¢ per scalp or tail was paid (Bailey 1895). By 1895, bounties were being paid in Iowa, North Dakota, South Dakota, and Minnesota. In these states, bounties often extended to include both pocket gophers and ground squirrels, which were also referred to as gophers. Since ground squirrels were more easily shot or trapped than pocket gophers, their number seemed to dominate in the submissions for payment.

A compulsory extermination law was passed in Kansas in 1905, however, the provisions of this law were seldom implemented. Several years later (1908), a bounty law was passed and, at the discretion of the counties, either 5¢ or 10¢ was paid for each scalp (Scheffer 1910).

These bounty programs were discovered to be very expensive and the counties soon found themselves unable to pay the claimants because of the large numbers of animals submitted for payment and a lack of funds. The number of fraudulent claims often compounded the exorbitant amounts paid out. Crouch (1933) indicated that it was not difficult for dishonest individuals to perpetrate fraud in claiming bounties on pocket gophers. He wrote, "Some public official to whom scalps or tails are presented for bounty may never have seen a pocket gopher, and it would be practically impossible for them to distinguish a dried and shriveled pocket-gopher scalp or tail from that of any other small animal." Frequently, several "scalps" or "tails" were fashioned from the skin of a single animal. A county clerk may unknowingly pay bounties on the scalps or tails of gophers collected outside the designated bounty area (Crouch 1933). Efforts toward paying bounties for pest animals often resulted in fraud and in some instances the corruption of officials.

The heavy drain on the public treasury usually resulted in the abandonment of such programs, resulting in the repeal of bounty laws. Because of the high cost, no county or state has ever been able to pay a generous bounty on rodents for any prolonged length of time. It was found that the expense of maintaining a bounty system was way out of proportion to the benefit resulting from a reduction in pest numbers. It is thought that the bounty systems, while they lasted, plus significant agricultural expansion, stimulated the development of gopher traps and gopher trap production. This contributed to the proliferation of gopher trap patents issued around the turn of the century and well into the early 1900s.

As the bounty systems were discontinued, they were often replaced with government sponsored poisoning programs in which farmers were provided with low cost or free poison bait and shown how to effectively use it. The poisoning programs were found much more cost effective and produced far greater results.

THE ART OF TRAPPING

The most effective method of setting a gopher trap is to place it in the main tunnel or runway, not in a lateral tunnel leading to the soil mound. The main tunnel is located by probing with a steel rod at a distance of about 14 to 18 inches from a freshly made mound on the side adjacent to the plugged hole. Fresh mounds are easily identified because the higher moisture content of newly dislodged soil makes the soil darker than older mounds. Fresh mounds are indicative of the most recent gopher activity and will maximize trapping success when traps are located near to where the gopher is currently digging. The main tunnel is generally about 7 to 10 inches below the surface; the reduced soil friction on the probe is the clue that indicates a tunnel has been entered. Alternatively, the main tunnel can be found by selecting two fresh gopher mounds and, with the assumption they are connected underground by a tunnel, proceeding to probe every 3 inches across the area of the suspected tunnel. Once the tunnel has been located, a shovel is used to open an approximately 12 inch diameter access hole to the tunnel. A hand trowel is used to clear any soil from the tunnel and to enlarge it slightly so a trap, such as the Macabee, can be inserted. To maximize results, two traps should be set in the main tunnel, each facing in the opposite direction (Figure 2). Traps need not be baited. Most trappers close up the trap hole, leaving only a small dime-size opening for light to enter. Gophers are caught when they come to investigate the disturbed area of the tunnel and plug the small opening.

The directions accompanying some traps show the trap set in lateral runs that lead to the surface mound and instruct the user to clean out the soil from the laterals with a large long-handled spoon and then place the set trap inside. While this method is simpler for the home gardener because it dispenses with the need to probe for the main tunnel, trapping success is considerably diminished. The lateral tunnels produce poorer results because they may be blocked with soil at some lower level. In fact, in many instances the gopher does not reuse the laterals, whereas the main tunnel is used on a regular basis. Professional gopher trappers rarely waste time setting traps in lateral runs.

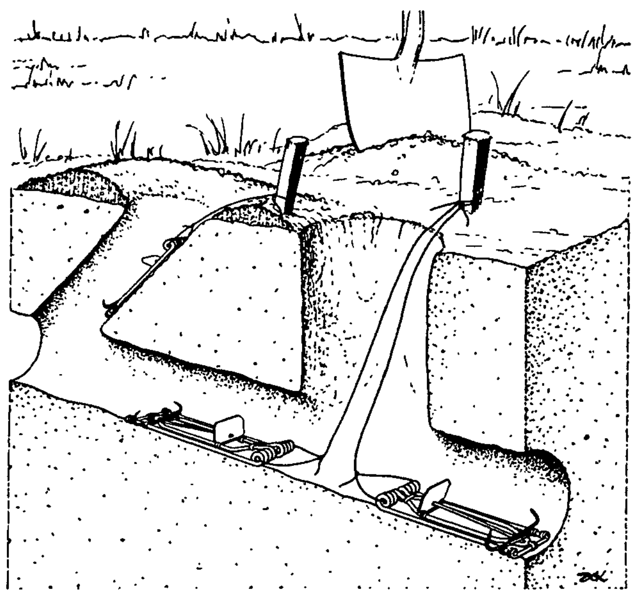

Figure 2. Two Macabee traps positioned in opposite directions in the gopher's main tunnel is the best of sets. The single trap positioned in the lateral tunnel (on the left) is a much less productive set.

EARLY USE OF LEG-HOLD TRAPS

Prior to the development of traps specifically designed for pocket gophers, small size leg-hold traps were found to be fairly effective for taking gophers. The "O" size was particularly useful, because it could be more easily inserted into the gopher burrow without much extra digging. Early records and writings indicate that such traps were in common use in the midwest by the 1860s. These traps would catch the gopher mid-body, killing it instantly.

Halsey Thrasher (1868), in his book entitled "The Hunter and Trapper," devoted a chapter, consisting of all of two pages, to the control of pocket gophers. He describes the animal and its activities. Thrasher wrote the following: "The best trap to use is the little one spring kind of the Newhouse make. Having pushed the trap in, go away, without further fixing, and perhaps in an hour, perhaps in three to four days, you will catch the lad."

Charles Olds, a salesman for the largest trap manufacturer in the country, reported back to his employer, the Oneida Community, the promising outlook for trap sales for the purpose of trapping gophers. According to Gerstell (1985), in 1867 Olds wrote of gopher problems in the Missouri and Mississippi valleys and added that bounties were being paid to destroy the pests. Olds further indicated that the new No. 0 traps were well suited to trapping gophers and that the majority of those purchased in Iowa were bought for that purpose (Gerstell 1985). The Newhouse pattern No. 0 trap was sometimes referred to in advertisements during that period as a rat and gopher trap because it was used mostly for those pests, or vermin, as they were frequently called in those days.

These accounts provide information regarding gopher trapping prior to the industrial revolution. Even after traps specifically designed for pocket gophers were being made and marketed, the use of No. 0 leg-hold-type traps continued to be commonplace. They also continued to be suggested in trapping guides (Kreps 1909) and in gopher control bulletins written for farmers. As an example, in a USDA Circular, Lantz (1908) wrote the following: "For trapping gophers an ordinary No. 0 steel trap may be employed with success, but there are on the market several special gopher traps which are better adapted for general use." Field studies conducted by Scheffer (1910) compared the trapping success of the No. 0 steel trap with those of the 44 California and Newhouse gopher traps. The percent catch was 36 for the 44 California, 30 for the No. 0 steel traps, and 19 for the Newhouse. In this particular field study, the No. 0 steel trap compared favorably to the best of the gopher traps.

EARLY GOPHER TRAP DEVELOPMENT

One of the earliest patented gopher traps was a choker-type box trap. It was patented in 1864 by Augustus J. Eddy and John B. Wilber of Iowa (patent number 45,399). Another wire choker gopher trap was patented by John Curtis of St. Charles, Minnesota (patent number 69,777); however, neither of these traps are known to have been produced commercially.

The first patented and commercially produced gopher trap that the author has identified is the Wood's gopher trap patented in 1870 by Romanso E. Wood of Santa Cruz, California (patent number 109,789). Based on early wholesale hardware catalogs, the "California" half-ring and strike-arm-type gopher trap was being marketed about this same period. William L. B. Cushing and Americus D. Vest of San Jose, California patented the CV Gopher Trap in 1884. The Catch-Well and Excelsior traps were patented in 1886 and commercially produced. A couple of years later, Bertie Jolly of Soledad, California developed the clutch-type trap and was issued patent number 375,822 on January 3, 1888. Frank White and Frank Murphy of Pomona, California patented the Suicide and Dead-Lock traps in 1890. The Ward's trap was developed and patented by Oring Smith Ward of Los Gatos, California in 1892. In 1896 Andrew C. Carlsen of St. Paul, Minnesota patented his Carlsen's spear-type gopher trap, and Charles M. Williams of Los Angeles, California fashioned and patented the Star trap in 1899. It is interesting to note how many of these traps were invented by California residents.

Collectively, a dozen or so gopher traps are known to have been marketed prior to 1900. Based on the number of hardware distributor catalogs which included them as listings, the Wood's and the "California" gopher traps appear to have been the most popular of the very early traps. By 1883, the makers of the Wood's trap claimed to have sold over 30,000 traps; presumably most were purchased in California. The CV and Ward's traps were apparently also fairly popular, and all remained on the market into the early 1900s (Marsh 1997).

THE RISE AND FALL IN TRAP DEVELOPMENT

Nineteen hundred through the 1930s was the zenith of gopher trap development; more traps were patented and commercially produced than during any other comparable period of time. During the first decade of the century, traps like the Macabee, 44 California, Newhouse, Gates, Merritt, OK, Hamilton, Hooker, Daniels, E-Z, and the Cinch were representative of what appeared on the market. The next 10 years produced such traps as the Eldridge, Brown's, Teeter, Renken, Salof, Death-Klutch, Bittle, J.V.J., and the Ideal. The 1920s brought the Ullman, Lutz, Palmer, Phillips, and Wolf double spring choker-type box trap. Representatives of the 1930s include the Circlaw, Superior, Lewis Pincer, M.W.G. Pincer, Victor, Hain's Double Pincer, and Get-Mor (Marsh 1997). In Figure 3, a selection of widely different types of gopher traps is illustrated to demonstrate the developmental ingenuity of trap inventors.

A wide variety of gopher traps were patented at a relatively fast pace from 1900 up until the beginning of World War II. After the war, a few new gopher traps, like the Self-Set, were commercially produced; but, by the late 1940s, little was happening in the field of trap development. Since the late 1940s, only a dozen or so new gopher traps have appeared on the market. The EasySet, the Quick-Set, the DK-2, and the Guardian represent some of the most common of these. The Blackhole, marketed in the late 1980s, has been the most successful of the more recently developed gopher traps. The Quick-Set, patented in the 1988, has received some interest, especially in the midwest (Marsh 1997).

Breaking into the current market with a new trap is fraught with difficulties, even if the trap is highly efficacious. The major problems are getting the trap into the appropriate distribution channels and producing a trap that can favorably compete in price. There appears no reason to believe the outlook for gopher trap development will change; it is most likely to continue at about the rate which has occurred over the last four decades.

TRAPS WITH A LONG HISTORY

In 1900, Zephyr A. Macabee of Los Gatos, California developed the highly acclaimed Macabee gopher trap that has survived relatively unchanged and is still manufactured to this day by the heirs of the inventor.

A few years later, about 1904, the 44 California choker box trap had its beginning; however, no patent has been identified for this trap. The 44 California was produced up until 1980 when it was discontinued.

The Newhouse gopher trap was first produced in 1901 by the Oneida Community, and continued to be manufactured, but not by the same firm, until about 1986 when it too was discontinued.

The Cinch trap, patented on November 8, 1910 by Charles A. Wyman of Gaston, Oregon, is another trap with a long history. It remains on the market today, however, it is believed that its production was curtailed for a time, but for how long is unknown.

The Death-Klutch was patented in 1917 by Judson C. Pewther and continues to be manufactured and sold. The Death-Klutch has been a popular trap in the midwest while the Cinch trap is popular in the west, especially the northwest.

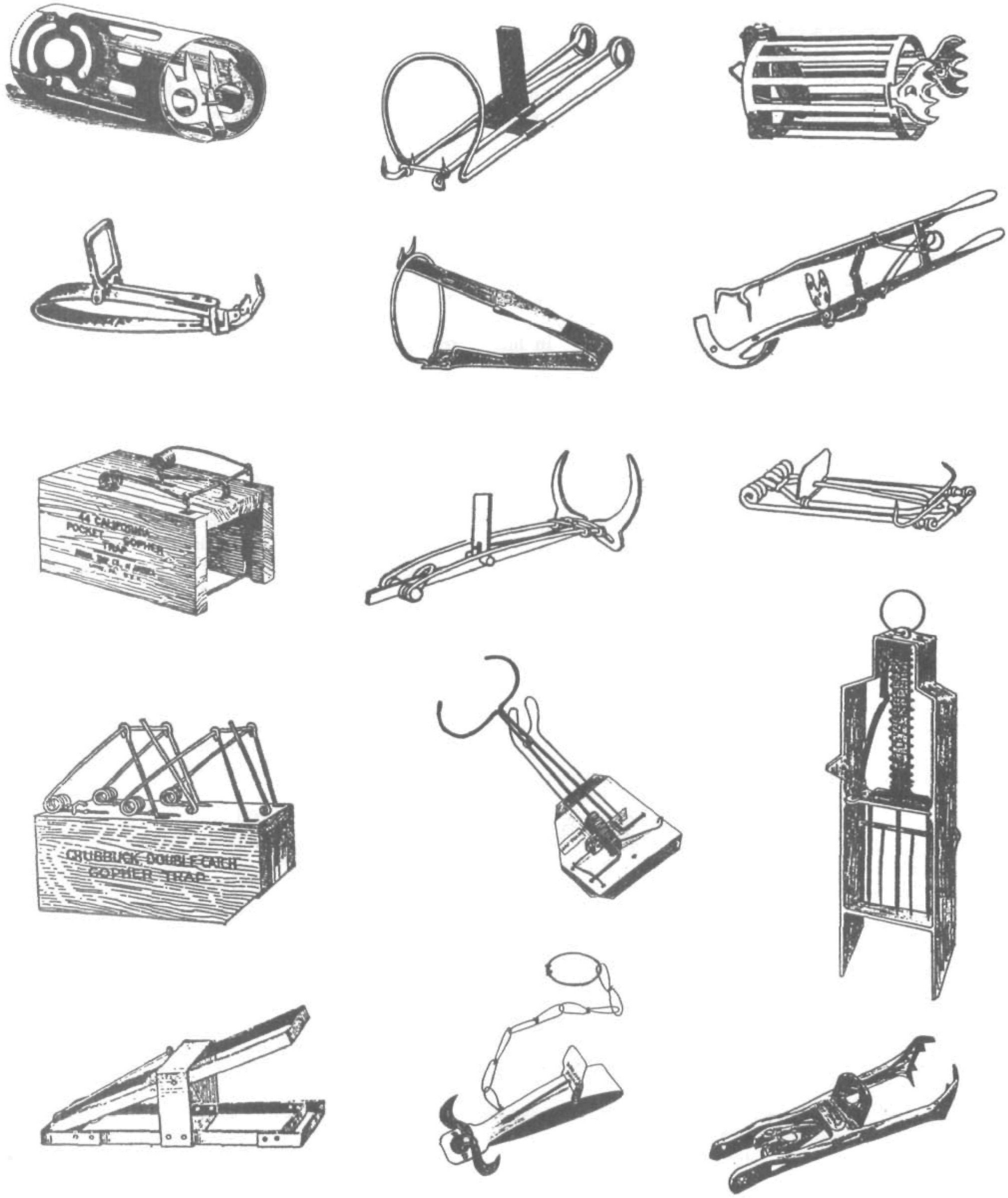

Figure 3. Illustrations of a variety of pocket gopher traps dating from about 1870. (Top row L to R) Wood's, Star, Ideal. (Second row L to R) Triumph, Newhouse, California*. (Third row L to R) 44 California, Ward's, Macabee. (Fourth row L to R) Double Catch, Zap*, "Dandy"*. (Bottom row L to R) Renken Sure Catch, Oneida Victor*, Self-Set*. Illustrations with an asterisk following the name of the trap were drawn by Ron Munro.

Thus, five pocket gopher traps have exceptionally long histories of production and use, ranging from about 80 to nearly 100 years. Of these, the Macabee, Cinch, and the Death-Klutch remain in production.

THE MACABEE GOPHER TRAP

In keeping with the title of this paper, it seems appropriate to highlight the gopher trap with the longest history of production. The tale of the Macabee gopher trap is, indeed, an example of a classic success story and one of which California is most proud. The small, family-owned manufacturing firm can claim nearly 100 years of production. Throughout this period, it has remained one of the best and most cost effective traps ever produced. Much of the following history of the Macabee trap has been drawn from a previous publication (Marsh 1997).

At the turn of the century, Zephyr A. Macabee of Los Gatos, California, a barber by trade, designed and patented the Macabee gopher trap. Patent number 659,932 was granted October 16, 1900. The commercial trap is almost identical to the patent drawings. Except for the use of a better grade of steel wire and some additional soldering, this trap has essentially remained the same over 98 years of production. Early in its history, the trap was made in two sizes; the regular size was 6 inches long and the large size was 6-5/8 inches long with a jaw spread of 2-3/4 inches when set. The current model is slightly shorter than the original regular size model.

A newspaper article about the Macabee trap and its makers, by staff writer, Joan Jackson, was printed on March 11, 1980 in the San Jose News. Information from that article revealed that the trap was still being produced in what was originally Zephyr Macabee's home, a Victorian house at 110 Loma Alta Avenue in Los Gatos. The home is now designated an historical landmark. When Z. A. Macabee first started the family business out of his home, the traps were made and assembled in the cellar. As the story goes, Z. A. Macabee traveled throughout the Santa Clara Valley in his horse-drawn wagon selling traps. This was at a time when the valley was becoming one of the leading fruit producing regions of the state. There were prune, apricot, cherry, pear, and walnut orchards covering much of the valley and pocket gophers were a major threat, especially to young orchards.

Z. A.'s children, Lucille Macabee Evans and Raymond Macabee, ran the family business after the death of their father. Raymond Macabee retired about 1979 and his children, Joyce Ridgely and Mary Barnes, took over the business with the assistance of Ron Fink, the production manager. At that time, the Z. A. Macabee Gopher Trap Company had a total of 10 workers.

The Macabee family moved to a new home in 1924, retaining the old residence on Loma Alta Avenue and continuing to utilize it as the firm's production plant. In 1980, piece work was conducted at home by some of the employees, but the actual assembly was still done in the cellar. The soldering was done in an old barn behind the house and the painting in another barn, which also served as storage. According to Ron Fink (pers. comm.), things have not changed much since 1980.

An advertisement for the Macabee trap found in the January 1904 issue of *California Cultivator* magazine mentions that, "If your dealer does not handle same, send 15¢ in stamps and mention your dealer's name and get sample at special rates." The Macabee gopher trap was a success almost from the beginning. It was highly touted by those experienced and knowledgeable in gopher control and was frequently mentioned in farmers' bulletins written specifically for the control of gophers or for the control of agricultural pest rodents in general, which always included gophers (Dixon and De Ong 1917; Dixon 1929; Storer 1938; Crouch 1942; Cummings 1962; Marsh 1992). Since its inception, the Macabee has been the leading gopher trap in the west and is especially popular with California growers. About 1960, it was said, based on distributor's reports, to have 75 to 80% of the gopher trap market. Macabee's main competitor at that time was the 44 California choker-type box gopher trap.

The Macabee and the 44 California dominated the California gopher trap market for well over 60 years. The 44 California gopher trap was discontinued by Woodstream Corporation in 1980, leaving the Macabee as the preeminent gopher trap on the market. While a few other gopher traps remain or have come on the scene, the Macabee continues to dominate and has no significant rival, at least among the growers in the west.

THE EVOLUTION OF GOPHER TRAPPING

The trapping of gophers on a substantial scale can be traced back to the 1860s when the "O" size Newhouse leg-hold traps were being sold for gopher control in the Missouri and Mississippi valleys. By 1880, motivated by the thought that there was sufficient need for a specialized trap designed for taking gophers, inventors developed and patented over 50 different traps prior to 1900. Of these, at least 10 were produced and marketed. The period from 1900 through the 1930s was the heyday of gopher trap development. This was thought to have been stimulated by the passage of bounty laws, as well as the great agricultural expansion into the west, where pocket gophers were a serious pest.

While formulations were available in the early 1900s for preparing poisonous baits for gophers, commercially prepared baits were not readily available. In the 1920s and 1930s, following the discontinuance of bounties, the federal government, state, or county agencies often came to the aid of the growers and prepared gopher baits at a central mixing facility. These baits were distributed locally at cost or as a free service. Because baiting was a more cost effective method of controlling gophers, this method gradually replaced much of the trapping, especially in production agriculture. This trend toward baiting gophers continued and became increasingly more important following World War II when labor costs were rising dramatically, making labor-intensive trapping too costly. While the emphasis on trapping has waned over the years in agricultural production, it has always held a prominent place in gopher control in home gardens and landscaped areas.

The status of gopher trapping in the 1990s can be summarized as follows: trapping remains extensively used by home gardeners to resolve their gopher problems.

Trapping continues to be used in agricultural situations where only a few gophers may exist over a relatively small area, and to clean out a few gophers that may have survived a poisoning program or have invaded from an adjoining property. In those instances where ineffective control is being achieved with currently available gopher baits, trapping and burrow fumigation are used as alternative control methods. Trapping has regained a somewhat greater importance with the high emphasis placed on integrated pest management (IPM). Where toxic pesticides are not considered an acceptable control option, such as with organic growers, then trapping becomes the logical alternative. Although trapping is not as widely used today as it once was, it continues to play an important role in gopher management. As the 21st century approaches, the author does not expect there will be a significant change in the status of gopher trapping.

ACKNOWLEDGMENTS

The author thanks Ron Munro for permission to use five of his drawings to illustrate examples of different gopher traps. The author is also most grateful to Ron Fink for his contribution of background information about the Macabee gopher trap.

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EVALUATION OF ACROLEIN AS A FUMIGANT FOR CONTROLLING NORTHERN POCKET GOPHERS

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ABSTRACT: Baker Performance Chemical Incorporated entered into a cooperative agreement with the National Wildlife Research Center to evaluate acrolein as a fumigant for controlling northern pocket gophers (*Thomomys talpoides*). In October 1996, a 44.5 ha (110 acre) irrigated alfalfa hay field was selected as the study site in Franklin County, Washington. Eight treatment units (TUs), six fumigated and two control, were established on the study site. On the six fumigated TUs, 58.9% of the sample plots were inactive, whereas, all sample plots (100%) on the two control TUs were active. The 58.9% mean reduction in pocket gopher activity on the six fumigated TUs was below the minimum efficacy standard of 70% established by the Environmental Protection Agency (EPA 1982). Possible reasons for the pocket gophers surviving the acrolein treatment are discussed.

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INTRODUCTION

In 1995, the Baker Performance Chemical Incorporated (BPCI) entered into a cooperative agreement with the National Wildlife Research Center (NWRC) to evaluate acrolein as a fumigant for controlling pocket gophers. Since the early 1950s, acrolein has been registered with the Environmental Protection Agency (EPA) as an aquatic herbicide. In 1992, O'Connell and Clark demonstrated its effectiveness as a fumigant for controlling California ground squirrels (*Spermophilus beecheyi*). They inserted 20 cc of acrolein into the burrow systems of ground squirrels and sealed the burrows. The ground squirrel population was reduced by more than 90%. Acrolein is now registered under the special local needs (SLN) section of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as a fumigant in eight western states for controlling ground squirrels. The BPCI wanted to expand the registration of acrolein as a fumigant to include pocket gophers.

To provide the required efficacy data to add pocket gopher claims to the registration label, a study protocol was drafted to outline the procedure for evaluating acrolein for controlling northern pocket gopher (*Thomomys talpoides*) populations in alfalfa. In October 1996, the study was conducted in Franklin County, Washington. The study site was established in an irrigated alfalfa field containing a high population of northern pocket gophers. Pocket gopher activity was monitored before and after the acrolein was applied underground. The null hypotheses tested were: 1) that the efficacy was the same on the fumigated and control areas; and 2) that pocket gopher activity was reduced to <70% on the six fumigated treatment units (TUs).

MATERIALS AND METHODS

Study Site Location

A 44.5 ha irrigated alfalfa field containing northern pocket gophers was selected as the study site. Its location was approximately 16.6 km southwest of Basin City, Franklin County, Washington. The elevation of the area was 198 m above sea level.

Weather

The mean maximum daytime temperature during the 14-day study was 12°C (range 9 to 16°C) and the mean minimum nighttime temperature was 0.8°C (range -1 to 7°C). Between October 16 and 29, 1996, measurable rain occurred on seven days, totaling 2.54 cm of moisture, and a trace occurred on October 23, 1996. On the days of fumigation, October 25 and 26, the highest daily temperature was 12°C and 11.6°C, respectively.

Treatment Unit Establishment

On October 16, 1996, eight treatment units were established within the alfalfa hay field. All TUs were square, measured 0.40 ha and flags defined their boundaries. To reduce pocket gophers residing outside each TU from immigrating onto the TU after fumigation, a 7.6 m buffer zone (BZ) surrounded each TU, and were fumigated as well. Combined, each TU and associated TU and associated BZ measured 0.62 ha. A minimum distance of 50 m separated each TU and its BZ from other TUs and their respective BZs.

Pocket Gopher Activity Measurements (Open-hole Index)

The open-hole index (OH) (Richens 1967; Barnes et al. 1970) was employed to measure the efficacy of the acrolein as a fumigant to control populations of northern pocket gophers. The OH index measures the presence or absence of a pocket gopher within an underground burrow system by relying on the pocket gophers' propensity to close any open burrow within its home range. Normally, in the fall season, only a single pocket gopher would occupy a burrow system. Access to the burrow was created by either opening a closed entrance covered by soil (mound), a feeder plug on the surface, or by probing the ground around a mound or feeder plug with a metal rod until a tunnel system was located and then making an opening. All open holes were marked with a flag. Forty-eight hours later, an examination of the open burrow was made to determine if a pocket gopher closed the burrow with a soil plug. A closed hole (i.e., soil plug) classified the burrow system as active. Conversely, a burrow system remaining open was classified as inactive.

Establishing Sample Plots

On October 17, 1996, all previous pocket gopher signs were erased by leveling the mounds and scraping soil over the feeder plugs on all eight TUs and their associated BZs. On October 18, 1996, the eight TUs were examined and all freshly constructed mounds or feeder plugs observed were flagged. On October 19, 1996, fresh mounds or feeder plugs continued to be flagged, and on each of three TUs (5, 6, and 7) 15 sample plots were established in areas containing fresh mounds or feeder plugs. Each of these sample plots was circular with a 5.21 m radius and measured 0.008 ha (1/50th acre). The center of each sample plot was marked with a numbered wire-stem flag and the boundaries of each sample plot were defined. No overlapping of the boundaries occurred among the sample plots. Then, on October 20, 1996, sample plots were established on TUs 2, 3, 4, and 8. On October 21, 1996 all new active mounds or feeder plugs on the seven TUs were flagged, including those in the BZ. Then, on October 22, 1996, the 15 sample plots were established on TU 1 and all fresh mounds or feeder plugs were flagged on the 120 sample plots on the eight TUs.

Pretreatment Open-hole Index

The next step in the OH index involved opening all flagged active burrow systems on the 120 sample plots. On October 23, 1996, all burrow systems associated with the fresh mounds or feeder plugs were opened on each sample plot. Pocket gopher closure of the open burrow systems on the eight TUs was recorded on October 25 (48h). Upon completion of the pretreatment OH index, fumigation began.

Fumigation of Burrows

The treatments (six fumigation, two control) were randomly assigned to the eight TUs. Then, a second random selection occurred that placed one control and three treated TUs in Block I and the remainder in Block II, as follows:

Block I	Block II
TU 5 control	TU 3 control
TU 1 treated	TU 4 treated
TU 2 treated	TU 7 treated
TU 6 treated	TU 8 treated

On October 25, 1996, before fumigation, the metering device on the acrolein applicator was calibrated to insert 20 cc of fumigant into each active burrow system. Blocks I and II were fumigated on October 25 and 26, 1996, respectively. On the acrolein treated TUs, each active burrow system was opened on: 1) the sample plots; 2) each active burrow system outside the sample plots but inside the TU; and 3) all active burrow systems within the BZ associated with each TU. After all active burrow systems were opened on a TU, fumigation occurred. If a burrow entrance opened up into a "T," then both sides of the "T" were treated with acrolein. After treatment with acrolein, burrow entrances were sealed with soil, and a flag was placed at the site. After fumigation, these flags were collected and counted to determine the number of application sites. In those burrow systems where the soil could come in contact with the acrolein, paper was placed at the opening of the burrow system before sealing with the soil. On the control TUs, the active burrow systems were opened as described for the fumigated TUs, but no acrolein was applied. Instead, all open systems were then closed with soil and flagged.

Post-treatment Open-hole Index

On October 26 and 27, 1996, the treated burrow systems on the 60 sample plots were reopened on each of Blocks I and II, respectively. Any fresh mounds constructed post-fumigation on the sample plots were also opened. On October 28 and 29, 1996, the number of opened burrow systems closed by pocket gophers was recorded for Blocks I and II, respectively.

Statistics

Pre- and post-fumigation, no variability occurred on the two control TUs as 100% of the sample plots were active. Only treated TUs displayed variability. The data from the six fumigated TUs for the open-hole index were combined to produce an overall mean estimate and 95% confidence limits for the reduction in pocket gopher activity.

RESULTS

Pretreatment Open-hole Index

Block I. Pocket gophers were active on all (100%) of the 60 sample plots. Overall, 367 holes were opened on 60 sample plots on four TUs. On the three TUs scheduled to be fumigated, pocket gophers closed 239 (92.3%) of 259 holes opened on 45 sample plots. Pocket gophers closed 101 (93.5%) of 108 holes that were opened on the 15 sample plots on the control TU. Pocket gophers closed 100% of the open holes on 32 (71.1%) of the 45 sample plots on three TUs scheduled to be fumigated, and on 11 (73.3%) of the 15 sample plots on the control TU.

Block II. Pocket gophers were active on all (100%) of the 60 sample plots. Overall, 372 holes were opened on 60 sample plots on four TUs. On the three TUs scheduled to be fumigated, pocket gophers closed 268 (94.7%) of 283 holes opened on 45 sample plots. Pocket gophers closed 78 (87.6%) of 89 holes that were opened on the 15 sample plots on the control TU. Pocket gophers closed 100% of the open holes on 39 (86.7%) of the 45 sample plots on three TUs scheduled to be fumigated and 7 (46.7%) of the 15 sample plots on the control TU.

Fumigation

A composite of all fumigated holes for Blocks I and II is summarized in Tables 1 and 2, respectively.

Postreatment Open-hole Index

Block I. Pocket gopher activity declined on the three TUs that were fumigated with the acrolein as 27 (60.0%) of the 45 sample plots were inactive, however, pocket gophers remained active on 15 of the 15 (100%) sample plots on the control TU. On the control TU, pocket gophers closed 88 (94.6%) of the 93 holes opened on the

Table 1. A composite of all fumigated holes for Block I.

TU Number and Treatment	Fumigated Holes			
	Sample Plots	Outside Sample Plots, but Inside the TU	Buffer Zone	Total
5 - control	101	47	45	193
1 - fumigated	73	9	23	105
2 - fumigated	95	29	62	186
6 - fumigated	70	29	32	131
Total	339	114	162	615
$\bar{x}$	84.8	28.5	40.5	153.8
SD	15.5	15.5	16.9	42.7

Table 2. A composite of all fumigated holes for Block II.

TU Number and Treatment	Fumigated Holes			
	Sample Plots	Outside Sample Plots, but Inside the TU	Buffer Zone	Total
3 - control	84	18	38	140
4 - fumigated	128	40	64	232
7 - fumigated	62	18	52	132
8 - fumigated	77	29	29	135
Total	351	105	183	639
$\bar{x}$	87.8	26.2	45.8	159.8
SD	28.4	10.5	15.4	48.3

15 sample plots. On the three fumigated TUs, pocket gophers closed 34 (14.2%) of 240 opened holes on the 45 sample plots. Also, declining on the fumigated TUs, was the number of sample plots where pocket gophers closed 100% of the opened holes. On the three fumigated TUs, 100% closure occurred on only 3 (6.7%) of the 45 sample plots. Whereas, on the control TU, pocket gophers closed 100% of the opened holes on 11 (73.3%) of the 15 sample plots.

Block II. Pocket gopher activity declined on the three TUs that were fumigated with acrolein as 26 (57.8%) of the 45 sample plots were inactive. However, pocket gophers remained active at 15 of the 15 (100%) sample plots on the control TU. On the control TU, pocket gophers closed 78 (95.1%) of the 82 holes opened on the 15 sample plots. On the three fumigated TUs, pocket gophers closed 38 (14.3%) of 265 opened holes on the 45 sample plots. Also, declining on the fumigated TUs, was the number of sample plots where pocket gophers closed 100% of the opened holes. On the three fumigated TUs, none (0.0%) of the 45 sample plots had 100% closure. Whereas, on the control TU, pocket gophers closed 100% of the opened holes on 12 (80.0%) of the 15 sample plots.

Statistics

The number of active sample plots compiled for both pre- and post-treatment are listed in Table 3.

Table 3. The number of active sample plots compiled for both pre- and post-treatment.

Fumigated Sample Plots			Control Sample Plots		
Plot Number	Pre-treatment	Post-treatment	Plot Number	Pre-treatment	Post-treatment
TU 1	15/15	6/15	TU 3	15/15	15/15
TU 2	15/15	4/15	TU 5	15/15	15/15
TU 4	15/15	10/15			
TU 6	15/15	8/15			
TU 7	15/15	4/15			
TU 8	15/15	5/15			
Total	90/90	37/90		30/30	30/30
Active	100%	41.1%		100%	100%
Inactive	0%	58.9%		0%	0%

The 95% confidence limits were calculated for the 58.9% reduction as follows: i.e., the 95% upper and lower confidence limits were 69.1% and 48.7%, respectively.

DISCUSSION

The first null hypothesis test was rejected because a difference occurred in pocket gopher activity post-treatment between the fumigated and control TUs. However, the second null hypothesis was not rejected as the mean reduction in pocket gopher activity was <70%. The 58.9% mean reduction with 95% confidence limits of 48.7% to 69.1% approached, but did not encompass the 70% minimum standard for reduction in pocket gopher activity that was established by the EPA for verifying efficacy of fumigants (EPA 1982).

The 58.9% reduction in activity observed in this study is the highest percent reduction reported for pocket gopher control with a passive fumigant. Passive refers to the fact that the gas diffuses on its own throughout the burrow system. The previously registered Animal and Plant Health Inspection Service (APHIS) 85 g 8-ingredient gas cartridge (EPA Reg. No. 56228-2) for controlling burrowing rodents has never exceeded a 30% reduction in northern pocket gopher activity. Two field studies have been reported for this gas cartridge—in Montana, Sullins and Sullivan (1993) reported only an 8% reduction in pocket gopher activity after they fumigated a minimum of 20 pocket gopher burrow systems with one gas cartridge each. In an Idaho study, Rost (1978) reported reductions on three TUs of 15%, 22%, and 30% with a mean reduction in pocket gopher activity of 22%. On each of these TUs, 20 pocket gopher burrow systems were fumigated with two gas cartridges each, one on each side of the point of entry.

The APHIS/WS recently registered a 145 g, two-active ingredient (sodium nitrate and charcoal) gas cartridge (EPA Reg. No. 56228-2). As partial fulfillment of the registration requirements, this cartridge was tested on northern pocket gophers. On three fumigated areas, pocket gopher activity declined 7.1%, 13.3%, and 30.8% for an average decline of 17.1% (Matschke et al. 1995). Because this gas cartridge failed to achieve 70% or greater control, pocket gophers were removed from the label.

Three other fumigants, methyl bromide, chloropicrin, and nitrocellulose film bombs were evaluated for controlling Valley pocket gophers (*Thomomys bottae*). Pocket gopher activity declined about 50% for each of these compounds (Miller 1954). Two other compounds that Miller tested were even less effective, Hydrocyanic acid gas (HCN) and carbon bisulfide (CS).

Efficacy (mortality) appears to increase when fumigants are forced into the pocket gopher burrow systems by external pressure; however, data to support this observation are limited. When auto engine exhaust was pumped into the burrow systems of plains pocket gophers (*Geomys bursarius*), mortality was observed in 11 (85%) of 13 animals that were radio-tagged (Matschke unpublished data). Plesse (1984) reported that exhaust from a rototiller gasoline engine along with the gas generated by the 8-ingredient gas cartridges (EPA Reg. No. 56228-2) proved lethal to valley pocket gophers, but no mortality data were presented. Blonk (1951) reported that calcium cyanide powder was more effective in killing pocket gophers when blown into a tunnel system with compressed air than when applied with a hand pump. He estimated that compressed air carrying the calcium cyanide powder traveled 45.7 m (150 ft) in the tunnel system in 1.5 minutes. The degree of control was not specified, but this method was promoted to replace trapping to control pocket gophers along canal banks in (Blonk 1951).

Factors which contribute to a 40% pocket gopher survival rate after acrolein treatment are unknown. Miller (1957) discussed several factors that might contribute to pocket gopher survival following such treatment with fumigants; the first was the extreme length of the burrow system with its network of side tunnels that the toxic gas must fill. Second, the tunnel is a closed system and contains dead air; and third, the toxic gas may be lost through absorption by the moist or porous soil lining the tunnel.

Regarding the first factor, not enough is known about the variability in the length of the burrow systems of northern pocket gophers. This raises the question of whether or not the pocket gophers that died inhabited only short burrow systems. The second factor may also have been a major reason for pocket gopher survival. The dead air in a closed burrow system delays the diffusion of the toxic gas, making it difficult to move through the tunnel system, even under pressure. If some distance exists between the point of entry of the acrolein and the pocket gopher, the animal may react by plugging off the burrow system before the fumigant reaches a lethal concentration. Regarding the third factor, a 58.9% reduction in pocket gopher activity in this study was recorded when a sandy soil covered the study site. Had this been a loam or clay soil, a greater reduction in pocket gopher activity may have occurred.

Reinvasion and dosage rate are two factors that could have influenced the results. But in this study, reinvasion was probably not a factor. Information from two previous studies where pocket gophers were kill-trapped support this concept (Matschke et al. 1996; Matschke et al. 1997). Pocket gophers were trapped for five consecutive days on 0.47 ha TUs, with a 7.6 m buffer zone surrounding each TU. No trapping occurred in the buffer zone. The data show trapping success declined over time. Among the total of 47 animals trapped on both studies, the number of animals trapped on days 1 to 5 was 18 (38.8%), 16 (34.0%), 10 (21.3%), 2 (4.2%), and 1 (2.1%), respectively. If reinvasion were a major factor, trapping success would not have declined from 38.8% to 2.1% during the five days. Also observed on both studies was the sharp decline of fresh mounds on the two TUs, and they were abundant in the non-trapped BZs. In addition, the BZ in the present study was fumigated and the length of time from fumigation to completion of the open-hole index was four days.

Based on limited data available from this study, the 20 cc acrolein dosage may be inadequate. The data from seven sample plots containing one hole each, representing just one burrow system for each sample plot, showed that only three (43%) out of seven sample plots were inactive after fumigation (Figure 1). When the dosage was increased to 40 cc (two treated holes per sample plot), seven (100%) out of seven of the sample plots were inactive, but these sample plots could have contained only a single burrow system each receiving 40 cc of acrolein. The data suggest that as the number of fumigated holes increases per sample plot, no corresponding increase in efficacy was observed (Figure 1).

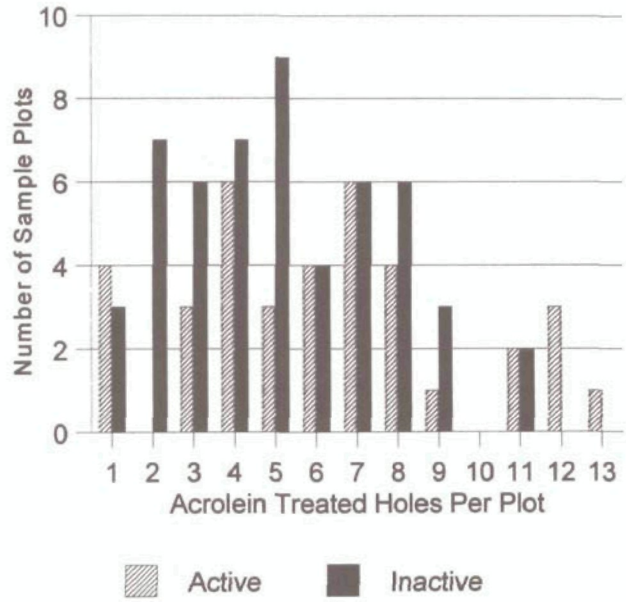

Figure 1. The relationship between the number of active and inactive sample plots and the number of treated holes per sample plot.

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MODIFIED BAIT STATIONS FOR CALIFORNIA GROUND SQUIRREL CONTROL IN ENDANGERED KANGAROO RAT HABITAT

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ABSTRACT: California ground squirrels are a major problem in areas that also support populations of endangered kangaroo rats. Traditional bait stations can be easily modified to exclude kangaroo rats, thereby providing landowners with a method of controlling ground squirrels that mitigates hazards to endangered kangaroo rats. Specifications for the design and use of modified bait stations are discussed.

KEY WORDS: California ground squirrel, *Spermophilus beecheyi*, elevated bait station, baiting, endangered kangaroo rats, endangered species

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INTRODUCTION

In central and southern California, ground squirrels (*Spermophilus beecheyi*) are a major problem in areas which also support populations of endangered kangaroo rats, namely the giant kangaroo rat (*Dipodomys ingens*), Fresno kangaroo rat (*D. nitratoides exilis*), Tipton's kangaroo rat (*D. nitratoides nitratoides*), and Stephens' kangaroo rat (*D. stephensi*). These kangaroo rat species now only comprise small, scattered populations, mostly occurring in close proximity to agricultural, grazing, or other developed lands (California Department of Fish and Game 1980; Williams and Kilburn 1992). The decline in these species and subspecies of kangaroo rats in California has been attributed to habitat fragmentation and loss through urbanization or agricultural development (California Department of Fish and Game 1980; O'Farrell and Uptain 1987; Kramer 1987, 1988; Williams and Kilburn 1992). Many kangaroo rat species now only comprise small, scattered populations, mostly occurring in close proximity to agricultural, grazing or otherwise developed lands. As a consequence, flooding, disease, loss of genetic diversity due to small population size and vertebrate pest control practices now threaten the continued existence of these populations. The risk of incidental poisoning of kangaroo rats with pesticides was addressed by the United States Fish and Wildlife Service (USFWS) in 1993 in a vertebrate pesticide Biological Opinion which proposed to severely limit rodenticide use on over 2.5 million acres of land to protect endangered species including the San Joaquin kit fox, blunt-nosed leopard lizard, and several species of kangaroo rats.

Control measures for California ground squirrels were severely impacted by these pesticide restrictions. Under the Biological Opinion, applications of zinc phosphide and anticoagulants (diphacinone and chlorophacinone) were prohibited within 100 yards of endangered kangaroo rat habitat. Use of fumigants (such as smoke cartridges) was permitted in the range of the species, but only by certified applicators trained to distinguish ground squirrel burrows from kangaroo rat burrows.

The Biological Opinion prompted a cooperative program involving Cal/EPA's Department of Pesticide Regulation, the California Department of Fish and Game, and the California Department of Food and Agriculture, to formulate mitigation strategies to allow control of California ground squirrels and other pest species in endangered species habitat. These strategies have been endorsed by USEPA and USFWS and incorporated into County Bulletins which are enforced by county agricultural commissioners.

A study was funded by the Vertebrate Pest Control Research Advisory Committee (California bait surcharge program) to: 1) conduct a literature review on the ecology and behavior of kangaroo rats in California ground squirrel habitat to determine impacts of rodenticides and fumigants on kangaroo rats and identify techniques to mitigate hazards; and 2) determine if bait stations could be modified to prevent access by kangaroo rats while still allowing ground squirrels to feed on bait.

LABORATORY AND FIELD TESTS OF MODIFED BAIT STATIONS

Reports of kangaroo rats climbing or jumping are limited to a few anecdotal accounts (Bartholomew and Caswell 1951; Eisenberg 1963; Kenagy 1972; Lemen and Freeman 1985, 1986; Williams 1992). Elevating the entrances to bait stations was, therefore, considered as a way to exclude kangaroo rats, while allowing access by California ground squirrels which are good climbers (Marsh 1994a). A number of designs for elevated bait stations have been proposed (R. Baker, pers. comm.), but the effectiveness of these stations in excluding kangaroo rats has not been well documented. Simple, low cost methods of modifying box and inverted "T" bait stations were considered.

Laboratory tests conducted at the University of California, Davis, determined that kangaroo rats can climb or jump to reach food when they are presented with a solid surface or means of climbing. Twenty Heermann's kangaroo rats, a species that is not endangered, were exposed to bait stations elevated in a variety of ways. All rats were able to jump to bait boxes elevated up to 60 cm (24 inches) high on concrete blocks. Even a 5 cm (2 inch) overhang added to the top of the concrete blocks failed to restrict access by kangaroo rats. Kangaroo rats also were able to climb to the bait stations when the platform was placed against a chicken wire fence, and when ramps to help ground squirrels climb to the bait boxes were added. However, bait boxes placed on table platforms with legs inset 5 cm (2 inches) proved to be inaccessible to kangaroo rats (Figure 1a). Similarly, kangaroo rats did not use inverted "T" bait stations that were modified by adding angled sections of pipe to elevate the entrances to 30 cm (12 inches) (Figure 1b). Results suggest that the potential for kangaroo rats to learn how to access these bait stations is low. These designs were the last to be tested in the laboratory so were tested with kangaroo rats that had already learned to jump or climb to box bait stations placed on concrete blocks.

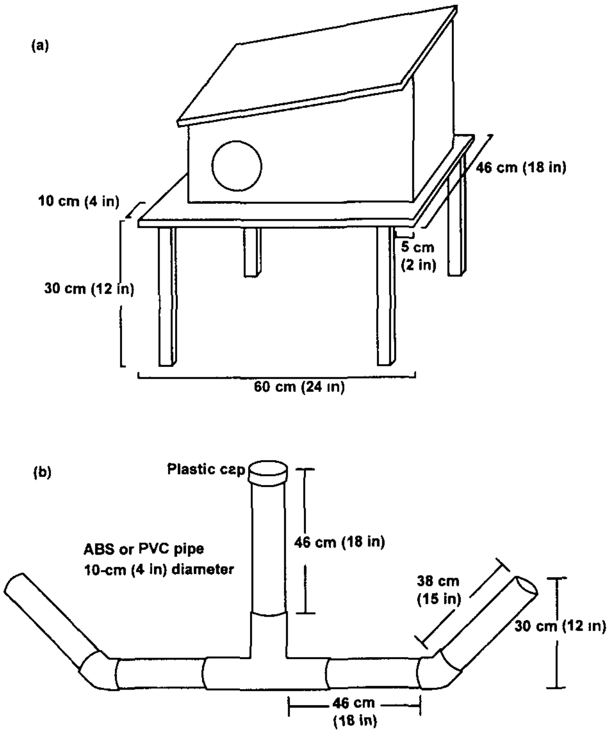

Figure 1. (a) Box bait station elevated on a table platform; (b) modified inverted "T" bait station.

The bait stations that excluded kangaroo rats in the laboratory tests were then tested for accessibility by giant kangaroo rats on the Elkhorn Plains, San Luis Obispo County in June and August 1996, and by Stephen's kangaroo rats on Lake Mathews Reserve, Riverside County in August 1996. Remote cameras were used to monitor visitors to the bait stations. Despite large populations of kangaroo rats in both areas, kangaroo rats did not visit modified bait stations. On the Elkhorn Plains, the only visitors to the modified bait stations were San Joaquin antelope squirrels during the day, and night visits by San Joaquin kit fox and rabbits. On Lake Mathews Reserve, bait stations were visited by rabbits.

Accessibility of the modified bait stations by California ground squirrels was tested on the University of California, Davis campus. Except for one inverted "T" bait station, California ground squirrels began visiting the modified bait stations within a week of their placement. The angled sections were removed from the bait station that had not been visited after two weeks. Once squirrels began visiting the unmodified station (within four days), the angled sections were replaced and squirrels continued to feed from the station.

BAIT STATION SPECIFICATIONS

Elevating box bait stations to ≥30 cm (12 inches) on table platforms or elevating the entrances to inverted "T" bait stations to ≥30 cm (12 inches) will reduce the risk of endangered kangaroo rats feeding on poison bait but still allow California ground squirrels to access bait. However, care must be taken to adhere to the following specifications:

1. Bait boxes should not be placed on a solid base. Kangaroo rats are able to jump or climb to heights of up to 60 cm (24 inches) if they are presented with a solid base. Even a platform top with a 3 inch (7.5 cm) overhang over a solid base is easily negotiated by kangaroo rats.
2. The legs of the platform should be inset at least 5 cm (2 inches) to stop kangaroo rats from climbing into the station. Ramps or wire mesh should not be added to improve accessibility by ground squirrels as kangaroo rats will learn to use these to climb into the bait station.
3. Other modifications to box bait stations may be necessary to prevent ground squirrels from spilling poison bait on the ground. The modified inverted "T" bait station has the advantage that bait is rarely spilled on the ground.
4. In rangeland where livestock are present, bait stations should be firmly secured to the ground to prevent them from being tipped over.
5. It is important to ensure that the vegetation is cleared from around the entrances. Kangaroo rats will be able to climb into the stations if dense vegetation is present or if the stations are placed against a ≤1.25 cm (½ inch) wire mesh fence. Keep entrances away from fence posts and large rocks that might be used by kangaroo rats to gain access.
6. Rain or use of sprinkler irrigators may result in water collecting in the bait stations causing bait to become moldy and less palatable to squirrels. In locations where this is likely, it may be necessary to further modify the bait station by adding an additional horizontal extension, or drilling a small hole in the bottom of the station to drain water, and to check bait stations more frequently to replace wet bait.
7. In kit fox range, the entrance to the station should be no greater than 7.5 cm (3 inches) in diameter. This can be achieved by fitting a 10 cm (4 inch) to 7.5 cm (3 inch) reducer or one-half an endcap.
8. In some instances, ground squirrels may take longer to discover the bait placed in modified bait stations. However, this problem may be solved by first placing an unmodified station containing clean grain. Once the squirrels begin feeding from the station, the station may be modified, poison bait added and the squirrels will continue to visit the station.

OTHER CONSIDERATIONS

Although kangaroo rats are excluded from poison bait placed in elevated bait stations, they still may be at risk of poisoning from bait cached by California ground squirrels. Because ground squirrels cache seed more frequently in late summer and fall (Marsh 1994b), limiting bait applications (in elevated bait stations) to late spring and early summer may reduce hazards to kangaroo rats. Moving modified bait stations from the perimeters of crops to a short distance inside the crop may further reduce the risk of incidental poisoning of kangaroo rats. Although ground squirrels establish colonies on the perimeters of crops, they will generally range and feed in the adjacent crop (Marsh 1994a,b). Conversely, most endangered kangaroo rat species have smaller home ranges (Eisenberg 1963; Price et al. 1994) and may be restricted to land that is not under regular cultivation (Best 1991; Williams 1992).

Although the presence of kangaroo rats complicates ground squirrel control, the ecology and behavior differences between the species make it possible to mitigate potential hazards to the endangered species. Differences in burrow size, and other burrow related characteristics of kangaroo rats and ground squirrels, enable fumigants to be selectively directed to only the targeted ground squirrels. The use of elevated bait stations and careful timing of baiting operations will minimize hazards.

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NOT ALL SIGMODONTINE RODENTS IN THE SUGARCANE FIELDS IN COASTAL VERACRUZ, MEXICO, ARE PESTS

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ABSTRACT: Rats and mice have traditionally been considered one of the most important pests of sugarcane. However, "control" campaigns are rarely specific to the target species, and can have an affect on local wildlife, in particular non-pest rodent species. The objective of this study was to distinguish between rodent species that are pests and those that are not, and to identify patterns of food utilization by the rodents in the sugarcane crop complex. Within the crop complex, subsistence crops like maize, sorghum, rice, and bananas, which are grown alongside the sugarcane, are also subject to rodent damage. Six native rodent species were trapped in the Papaloapan River Basin of the State of Veracruz; the cotton rat (*Sigmodon hispidus*), the rice rate (*Oryzomys couesi*), the small rice rat (*O. chapmani*), the white footed mouse (*Peromyscus leucopus*), the golden mouse (*Reithrodontomys sumichrasti*), and the pigmy mouse (*Baiomys musculus*). In a stomach content analysis, the major food components for the cotton rat, the rice rat and the small rice rat were sugarcane (4.9 to 30.1%), seed (2.7 to 22.9%), and vegetation (0.9 to 29.8%); while for the golden mouse and the pigmy mouse the stomach content was almost exclusively seed (98 to 100%). The authors consider the first three species to be pests of the sugarcane crop complex, while the last two species are not.

KEY WORDS: rodents, sugarcane pests, non-pest species, Veracruz

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INTRODUCTION

Rodents have traditionally been considered one of the most important pests in the agricultural areas of the Papaloapan Basin in Veracruz, México, affecting such diverse crops as sugarcane, rice, corn and sorghum (Reiss 1976). Among the pest species are the pocket gophers (*Orthogeomys hispidus*) (Family: Geomyidae), the cotton rat (*Sigmodon hispidus*), the rice rat (*Oryzomys couesi*), and the small rice rat (*O. chapmani*). Farmers also consider small rodents such as the pigmy mouse (*Baiomys musculus*) as species that cause damage to crops. Carrasco and Abarca (1962) refer to the following species as crop pests, particularly in the sugar cane of México: *Sigmodon hispidus toltecus*, *Sigmodon. hispidus. major*, *Peromyscus leucopus texanus*, *Peromyscus. boylii levipes*, *Peromyscus. latirostris*, *Oryzomys couesi acuaticus*, *Liomys irroratus*, and *Reithrodontomys fulvescens*.

The Papaloapan Basin contains an extensive sugarcane monoculture that has been in existence for at least 40 years. During this time, certain rodent species have acquired a pest status, and the present traditional rodent control strategies have been developed. However, there are concerns regarding the effectiveness of these traditional control strategies, in particular, with regard to ineffective damage surveillance, delay between identification of damage and treatment, and the use of inappropriate rodenticides such as warfarin and zinc phosphide. Where such compounds are used extensively, and in particular where the poisons are applied using aircraft, there is a concern that non-target species may be adversely affected (Hudson, Tucker and Haegele 1984; Janda and Bosseova 1984).

The objective of this study was to identify and separate the target rodent pest species from the non-target species, and to identify patterns of food utilization by the rodents in the sugarcane crop complex.

MATERIALS AND METHODS

Study Site

This study was undertaken in the State of Veracruz, where sugarcane is the major crop, representing 70% of the cultivated area and responsible for 28% of the country's total sugar production. The study site is situated between La Tinaja and Cd. Alemán (18°08'to 18°20'W, 95°55' to 96°20'N) and the sugar mill is at Tres Valles. The site is approximately 40 m above sea level and has a total area of 22,000 hectares.

The climate is predominantly subhumid and hot, with monthly rainfall in the range of 12.5 to 470 mm, an average annual precipitation of 2026 mm, and a mean annual humidity of 82.5%. There are two major clearly defined seasons: a rainy season (May to October), with an average rainfall of 1829.2 mm, and a dry season (November to April) with an average rainfall of 196.9 mm.

The crop complex of the Papaloapan Basin is dominated by sugarcane, interspersed with a mosaic of other crops, including maize, sorghum, rice, banana and mango, as well as grasslands and other uncultivated areas. Abandoned fields are widely distributed over the whole area. The sugarcane is burnt by the farmers prior to harvest to facilitate cutting and transportation. Thus, during harvest time, extensive areas are systematically cleared of vegetation.

Maize, sorghum, rice and bananas are crops grown during the rainy season. Maize is a subsistence crop and covers a low percentage of the cultivated area in the region, while sorghum is a highly profitable crop. Rice is grown in extensive areas, often alternating with the sugarcane. Harvest time for the rice is at the end of the rainy season (late October and November). Cattle raising is also an important agricultural practice in the region.

Sampling of Rodents

Four areas were identified in the study site (A, B, C and D), and within each area four sub-areas were marked out, each consisting of the interface between the sugarcane crop and adjacent crop vegetation.

Rodents were trapped each month between May 1994 and April 1995, using large snap traps, baited with fresh sugarcane. At each sub-area, the traps were set in two approximately straight lines, one in the sugarcane and one in the adjacent crop. Each line consisted of 40 traps set at 10 m intervals. On each trapping event, traps were set overnight between 1800 hrs and 0500 hrs the next day, over a three-day period.

Upon capture, each rodent was identified and classed as adult or immature, according to its weight and length. Biometric measurements recorded include total length, vertebrate tail length, hind foot length, ear length, weight and sex. Female reproductive status, and if pregnant, the number of embryos present was also recorded.

Stomach Content Analysis

Traps were checked early in the morning (0500 hrs) to safeguard stomach contents and to avoid damage to the animals by carnivorous ants. Stomachs were removed, preserved in 70% ethanol, and returned to the laboratory for processing. The examination of the stomach content was performed in a Petri dish using a dissecting microscope (14x magnification).

Sugarcane Cycle in the Area

In this area, sugarcane is planted from December until the end of May. From May to November the average age of the sugarcane increases from 4 to 12 months. This time period also corresponds with cane processing at the Mill. Vehicle access into the plantations probably restricts milling activity at other times of the year. However, harvest of the sugarcane is performed when the cane has a high sucrose content, and this is determined analytically within the laboratories at the Mill.

Plant Cover

A number of plant species were found growing either in association with the crop plants, in uncultivated areas or in grasslands. Such species included: *Rottboellia exaltata*, *R. cochinchinensis*, *Panicum maximum*, *Panicum bulbosum*, *Paspalum fasciculatum*, and *P. conjugatum*, *Setaria geniculata*, *Echinochloa colonum*, *Eleusine indica*, *Schizachyrium brevifolius*, *Poa pratensis*, *Sorghum halapense*, *Rhynchelytrum roseum*, *Digitaria sanguinalis* (Poaceae), various ferns, vines such as *Ipomoea purpurea*, ground tomatoes *Physalis angulata*, and *Solanum nigrum*, *Parthenium* sp., and various sedges, among them *Cyperus rotundus*, *Dactylis glomerata*, and *Cynodon dactylon*. Probably the most abundant plants were the touch sensitive *Mimosa pudica* and *Mimosa ivisa*, and the most troublesome weed in the area was the Kelly grass (*Rottboellia cochinchinensis*) to be found as an invader in all habitats.

Data Analysis

For each rodent species collected, the percentage of each category of food in the stomach was calculated. The data was analyzed independently over three periods of four months that were considered to reflect distinct growing phases of the sugarcane and prevailing climatic conditions (Table 1).

Data analysis was performed using SAS Version 6.11 for Windows, by Analysis of Variance, and by the Students T-Test.

RESULTS

Rodents of the Area

The six native species caught in the sampling area were:

cotton rat	*Sigmodon hispidus*
rice rat	*Oryzomys couesi*
small rice rat	*Oryzomys chapmani*
white-footed mouse	*Peromyscus leucopus*
golden mouse	*Reithrodontomys sumichrasti*
pigmy mouse	*Baiomys musculus*

Capture Success

The capture success of the six native rodent species caught in the study site from May 1994 to April 1995 are presented in Table 2. A total of 1,606 rodents were captured, of which over 72% were *Sigmodon hispidus*, 12.5% were *Oryzomys couesi*, and 9.2% were *Oryzomys chapmani*.

Apart from the capture of two specimens of *Baiomys musculus* in May 1994, the capture of each rodent species on a monthly basis is presented in Table 3. *Sigmodon hispidus* is seen to be the most prevalent rodent species in the study area for the whole of the study period. The number of animals trapped was stable between May and October 1994, but then increased between November 1994 and January 1995, and then decreased markedly in February 1995. There was evidence of a similar peak with both *O. cousei* and *O. chapmani*, although the magnitude was much less, reflecting the population size supported by this habitat.

Habitat Utilization

The percentage of each rodent species trapped in each vegetation type is shown in Table 3. The greatest proportion of each species were trapped in sugarcane, although this does in part reflect the greater trapping intensity in the sugarcane crop. Interestingly, for *S. hispidus*, uncultivated areas achieved a trapping success second only to sugarcane, probably indicating the importance of this habitat type for this species.

Diet

The results of the stomach contents analysis are as follows:

S. hispidus—sugarcane was found to be an important constituent in the diet, particularly between November and January, the maturing stages of the crop's growth (Table 4). Seeds and vegetation were also found to be important constituents of the diet.

O. cousei and *O. chapmani*—sugarcane was also an important dietary constituent, again particularly between November and January (Table 5). However, for *O.*

Table 1. Calendar periods of data analysis indicating climatic season and growth phase of the sugarcane.

Period	Calendar Months	Season	Sugarcane Cycle
1	May to August	Rainy	Early Growth
2	September to December	Intermediate	Late Growth
3	January to April	Drought	Harvest

Table 2. The capture success of the six native rodent species caught in the study site from May 1994 to April 1995.

Species	May to August	September to December	January to April	Total	%
Sigmodon hispidus	344	487	335	1,166	72.6
Oryzomys couesi	56	105	39	200	12.4
Oryzomys chapmani	47	65	36	148	9.2
Peromyscus leucopus	17	15	8	40	2.5
Reithrodontomys sumichrasti	30	13	8	51	3.2
Baiomys musculus	2	0	0	1	0.1

Table 3. Patterns of habitat selection for *S. Hispidus*, *O. couesi*, *O. chapmani*, *P. leucopus*, *R. sumichrasti*, and *B. musculus* within eight habitats.

Species	Sugarcane	Sorghum	Maize	Banana	Rice	Mangoes	Uncultivated Areas	Grazing Areas
S. hispidus	64.83	0.60	3.94	1.54	4.28	0.69	23.07	1.02
O. couesi	87.19	0.00	0.98	0.98	2.95	2.03	7.36	0.49
O. chapmani	77.70	0.67	2.70	0.00	4.05	2.07	12.83	0.00
P. leucopus	40.00	17.00	2.38	7.40	4.76	12.16	2.38	5.00
R. sumichrasti	66.66	11.76	15.68	5.88	0.00	0.00	0.00	0.00
B. musculus	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00

Table 4. A comparison of the >50%< volume consumed by *S. hispidus*, *O. couesi*, *O. chapmani*, *P. leucopus*, *R. sumichrasti*, *B. musculus* in May 1994 to April 1995.

Species	Sugarcane <50% >50%	Seeds <50% >50%	Vegetation <50% >50%
S. hispidus	32.44 - 6.60	22.04 - 4.60	2.74 - 0.93
O. couesi	4.86 - 0.00	9.21 - 0.24	0.12 - 0.00
O. chapmani	2.40 - 0.06	6.03 - 0.31	0.18 - 0.00
P. leucopus	0.27 - 1.36	0.68 - 0.43	0.00 - 0.00
R. sumichrasti	0.00 - 0.00	2.98 - 0.06	0.12 - 0.00
B. musculus	0.00 - 0.00	0.00 - 0.12	0.00 - 0.00

Table 5. Seeds, sugarcane (Sc.), and vegetation (Veg.) consumption during the three four-month periods.

Species	May to August			September to December			January to April		
	Seeds	Sc.	Veg.	Seeds	Sc.	Veg.	Seeds	Sc.	Veg.
S. hispidus	8.20	6.91	1.80	10.20	14.30	0.62	3.60	11.30	0.31
O. couesi	3.23	0.00	0.12	4.85	1.68	0.00	1.12	0.18	0.00
O. chapmani	0.12	0.43	0.60	0.12	0.74	0.00	0.18	0.80	0.00
P. leucopus	0.37	0.24	0.06	0.12	0.12	0.00	0.18	0.00	0.00
R. sumichrasti	1.86	0.00	0.12	0.43	0.00	0.00	0.62	0.00	0.00
B. musculus	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00

cousei, seeds were an important dietary component over the whole study period, while for *O. chapmani*, invertebrates were an important dietary component.

P. leucopus—invertebrates and vegetation were important dietary components, while for *R. sumichrasti* and *B. musculus*, the diet was almost exclusively seeds.

DISCUSSION

It is thought that rodents can influence grassland ecosystems through their feeding habits (Golley 1975) with selective consumption of seeds influencing species composition and plant cover. It is thought that *Sigmodon hispidus* and both species of *Oryzomys* live in grasslands and fallow fields at times of the year when the crops are not providing an available food supply, moving into the sugarcane fields as the ripening season of sugarcane approaches, then leaving them after they damage the crop extensively. The other species of rodents generally stay in the fallow fields, where a great amount of food is to be found as well as insects. Probably as important as food, is the availability of refuges so common in the fallow fields.

The relationship between high rodent density and quality of habitats is positive. It was observed that sugarcane habitats were preferred specially by *S. hispidus*, *O. couesi*, and *O. chapmani*. Nevertheless, the uncultivated areas were also preferred first by *S. hispidus*, and second by *O. couesi* and *O. chapmani*. Glass and Slade (1980), Kincaid and Cameron (1985), Kincaid, Cameron and Carnes (1983), Lidicker, Wolf, Lidicker and Smith (1992), and Spencer and Cameron (1983) show that cotton rats occupy differing habitat associations during the different seasons. Cockburn (1981) and Taylor (1984) considered that alternate habitat occupancy may reflect preferences for or avoidance of particular forage species. Several studies suggest that hispid cotton rats select a mixture of dietary items from different habitat patches to balance their intake of nutrients (Kincaid and Cameron (1982, 1985), McMurry, Lochmiller, Boggs and Leslie (1994), and Randolph, Cameron and Wrazen (1991) suggest that dicot plants may be essential because they are richer in nutrients, energy, and water, and monocots provide a source of soluble carbohydrates and fiber, are more abundant, and have lower handling cost. Protein and phosphorous are nutrients likely to limit reproduction of *S. hispidus* (Randolph, Cameron and McClure 1995). Farmers believe that in the middle and at the end of the dry season rodents use sugarcane as a source of water. Nutritionally, sugarcane is a poor food source for rodents as digestibility is extremely low (Garrison and Breidenstein 1970). The pith of sugar cane contains approximately 70% free water and 30% dry matter consisting of cellulose and sucrose. Crude protein represents only 1.2% and 2.2% in the pith and rind, respectively (Garrison and Breidenstein 1970). Conversely, the dominant weeds of the area can contain 10 to 20% of crude protein depending on the conditions under which they grow (Negus and Pinter 1966).

Svihla (1931) mentions that *O. couesi* and *chapmani*, under natural conditions, fed chiefly upon the seeds and succulent parts and sedges, and noted that each rice rat *O. palustris texanus* consumed 23.8% of its live weight per day. Meserve (1971), studying *Oryzomys longicaudatus* mentioned that this mouse, during the dry season (January to May), showed a strongly granivorous diet (proportion of seeds: 72.7%, of which more than two-thirds was grass and forb seeds). During the wet season they show a remarkable specialization of feeding on flowers, pollen and foliage (53.3%). The authors considered that *S. hispidus, O. couesi*, and *O. chapmani* are the only rodent pests in the sugarcrops in this area of México. It is important to mention that *P. leucopus* and *R. sumichrasti* are seed consumers, and sugarcane is rarely found in their stomach contents.

CONCLUSIONS

Due to the rare presence of sugarcane in their stomachs and the fact that they are rarely captured inside sugarcane fields, and due to the fact that they cannot open a mature sugarcane stalk because of the inherent hardness and thickness of the rind, it is concluded that *Peromyscus leucopus*, *Reithrodontomys umichrasti*, and *Baiomys taylori* (the smallest rodent of the continent), are not involved in the damage to sugarcane crops. The authors consider that *S. hispidus*, *O. couesi*, and *O. chapmani* are the major rodent pests of the sugarcane fields of this area of Veracruz. The minor rodent pest in the whole area is the hispid pocket gopher (*Orthogeomys hispidus*) rarely found in the sugarcane fields. Therefore, the authors suggest that rodent control campaigns based on the use of poison baits be directed to the target species.

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NORWAY RAT EXCLUSION IN ALBERTA

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ABSTRACT: Since 1950, Alberta Agriculture has supervised and coordinated a rural-based Norway rat (*Rattus norvegicus*) control program that has essentially kept the province rat-free. Success is achieved by eliminating invading rats within a control zone 600 km long and 30 km wide along the eastern border of the province. A systematic detection and eradication system is used throughout the zone to keep rat infestations to a minimum. Strong public support and citizen participation was developed through public education and a sound awareness effort. Although rat infestations within the interior are minor, a rat response plan is in place to deal with a large or difficult case. Government preparedness, legislation, climate, geography, effective rat baits and close cooperation between provincial and municipal governments have contributed to program success.

KEY WORDS: Agricultural Pests Act, Norway rat, eradication, sylvatic plague, toxicants, anti-coagulant, arsenic, scilloricide, Warfarin, antu, thallium sulphate, barium carbonate, strychnine, zinc phosphide, compound 1080, carbon monoxide, boreal forest, detection, eradication, firearms, ground squirrel, pocket gopher

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INTRODUCTION

Norway rats (*Rattus norvegicus*) first arrived in North America along the eastern seaboard about 1775 on board steerage and merchant sailing vessels. Rats spread westward over the continent accompanying human settlement (Hall and Kelson 1959), entering upper Canada in the early 19th century (Ontario Provincial Archives). About 100 years later, rats entered the Canadian prairies through Saskatchewan from the mid-west United States. Within 10 years following World War I, rats had reached central Saskatchewan, and World War II spanned the province to the eastern border of Alberta.

Rat migration into Alberta was stopped along the eastern border by a well organized and managed program of eradication. Alberta's rat control program continues today in halting the westward advance of rats into the province.

This paper describes the history, current status and strategies of rat control, the future of rat control in Alberta, and the factors which contributed to the success of the program.

Reference data were cited from departmental, as well as divisional, annual reports from Alberta Agriculture, Food and Rural Development and from original documents and files of the Departments of Alberta Agriculture and Saskatchewan Agriculture, 1950 to 1983.

HISTORY

Wild Norway rats were first discovered in Alberta during a Department of Health epidemiology field survey along Alberta's eastern border. Field crews conducting sylvatic plague (*Yersinia pestis*) studies on Richardson's ground squirrel (*Spermophilus richardsonii*) uncovered, by chance, a rat colony on a family farm near the community of Alsask in central Alberta.

Department of Agriculture

Report of the findings brought immediate action by the provincial government, which was concerned about rats as possible vectors of sylvatic plague. A decision was made to halt the westward migration of rats into the province. As a result, in 1950, responsibility for rat control was transferred to the Department of Agriculture.

The Department's Agricultural Pests Act of 1942 authorized the Minister of Agriculture to name any pest that was likely to contaminate or destroy any crop, stored grain, feed, and foodstuffs. The regulations of the Act required that all persons and municipalities, rural and urban alike, were to take active measures to destroy, control, and prevent pests, such as rats, on their property. Fortunately, provincial legislation to eradicate pests was in place before rats entered Alberta and became effective when rats were declared a pest in 1950.

Rat Control Zone

Departmental officials had the foresight and determination to eradicate rats and quickly established a rat control zone (RCZ) that included all the farm land infested with rats (Figure 1). The north-south dimension of the control zone extended from the Alberta-Montana border in the south to the relatively uninhabited boreal forest region of the north, a distance of 610 km (380 miles). The width of the zone was three survey ranges west from the Alberta-Saskatchewan border, a distance of 29 km (18 miles).

Training and Education

Most Albertans had no experience with, or knowledge of, Norway rats or how to prevent or control them. The Department responded by developing a public relations campaign aimed at educating the public, detailing rat control objectives, and mustering support from all levels of government, industry, and the rural community.

Control Methods

Rat control methods in 1951 included the destruction of rat colonies, elimination of rat harborages and potential food sources, and rat-proofing farm buildings and rural structures. The recommended toxicants were arsenic, red squill (scilloricide), antu, thallium sulfate, barium carbonate, zinc phosphide, strychnine alkaloid, and compound 1080. Rat snap traps, carbon monoxide gas, and shooting were also used. At that time, anti-coagulant baits had not been commercially developed for rat control; although Warfarin had been discovered, it was still new and relatively untested.

Figure 1. Rat Control Zone in eastern Alberta.

The Department did not have the necessary skills and expertise to control rats, so in 1952 the Department hired a private pest control firm to arrest the westward movement of rats.

From 1952 to 1953, over 60,000 kg of arsenic trioxide (73%) tracking powder was placed under 8,000 buildings on nearly 3,000 farms. This undertaking proved to be too expensive, and due to rising concerns about risk to non-target animals such as livestock and poultry, was discontinued. However, the quick knock-down of rat populations and termination of rat migration gave the Department time to organize a sound rat control program.

Provincial-Municipal Cooperation

The Department, in cooperation with the several municipalities along the eastern border, developed a universal strategy of detection for and control of rats on agricultural land. All farmsteads, nuisance grounds, and other potential rat habitat were identified as inspection sites and were to be inspected regularly and consistently throughout the year. Some locations were to be inspected more than once, depending on proximity to nearby infestations and distance from the eastern border. This organized and systematic strategy of rat presence was the mainstay of rat control and is still practiced today.

During the 1950s, upwards of 25 municipal Pest Control Officers (PCO) were hired to conduct rat control within the RCZ. In addition, 250 PCO's were appointed as municipal pest control officers throughout provinces' rural and urban municipalities as required by law.

Until 1975, the Department of Agriculture and the partnering municipalities shared equally in the cost of rat control. Since then, the Department has paid 100% of the total cost of the rat control program.

As an incentive for others to participate in the rat control program, the Department offered rat bait and other related control materials and manpower assistance to landholders and municipalities free of charge.

The Department produced several campaign posters, visual displays, preserved rat specimens, pamphlets and publications, as well as warning posters, report forms and other incidental documents to report and record rat control activities.

PRESENT DAY RAT CONTROL PROGRAM

Today, the rat control program operates essentially the same way it did over 40 years ago. The major differences today are the workforce is smaller, fewer farmsteads, improved road systems, and better communications and control agents.

Within the RCZ, rat control is carried out with six man-years of labor in half the original number of municipal jurisdictions involved in the rat control program.

While rat control field operations are still the responsibility of the municipalities within the RCZ, the provincial government continues to provide resource support, complete funding, and overall administration and superintendence of the program.

Although rats continue to invade Alberta, reported rat infestations continue to decline (Figure 2).

Today, over 90% of all reported rat infestations occur on actively occupied land (Figure 3). Furthermore, nearly all rat infestations are located within less than one km of abandoned farm structures where equally available resources exist, but where rats are absent.

To improve the accountability of provincially funded programs, the two levels of government entered into written contracts clarified the roles and responsibilities of both parties.

FACTORS AFFECTING RAT CONTROL

Natural Barriers

The occurrence of Norway rats is directly dependent upon the presence of people. In Alberta, the distribution of people is largely determined by vegetation type and geography, which also acts as a barrier from invading rats. The province is protected from rat invasion in the south by open, relatively unsettled short-grass prairie, in the north by boreal mixed-wood forest, and in the west by the Rocky Mountains. The only route of invasion is overland from the east along a sparsely populated rural area; itself a limiting factor to rat migration.

Weather

Probably the most influential natural factor affecting rat invasion in Alberta is the temperate and inhospitable climate of the western prairies. For about half the year the province is snow covered with daytime temperatures well below-freezing. The harsh climate limits rat activity to occupied, man-made structures and discourages rat colonization in isolated areas.

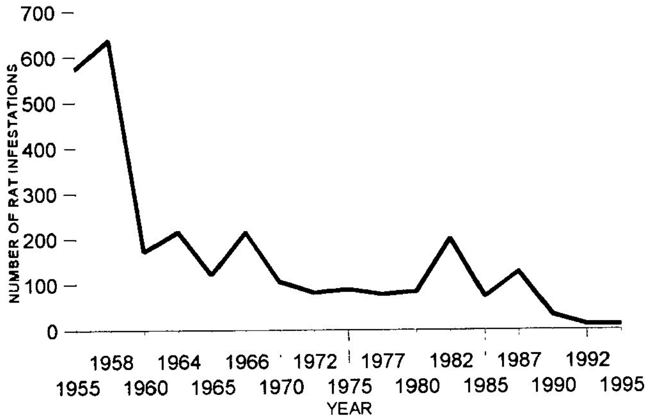

Figure 2. Number of rat infestations in Alberta, 1955 to 1995.

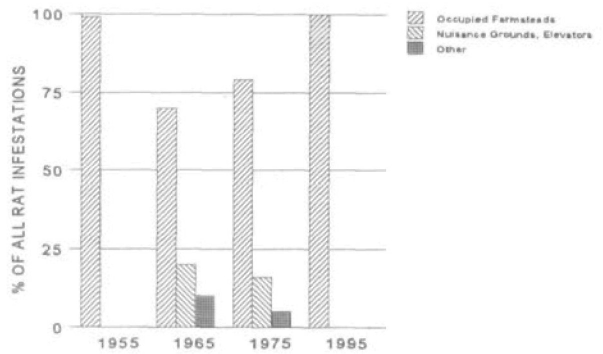

Figure 3. Distribution of rat infestations in Alberta, 1955 to 1995.

Rat Control Zone

The size of the rat control area (6840 sq. mi.) is relatively small compared to the rest of the province (246,422 sq. mi.). If rats had spread to the rest of the agricultural sector, as has occurred in other western provinces, control would probably not have been attainable.

Desire to Eradicate Rats

From the beginning, authorities and residents were determined to keep the province free of rats and have done it for over 45 years, in spite of the fact that several outbreaks occurred as far west as 150 miles from the RCZ.

Legislation

Provincial authorities had appropriate legislation in place before rats invaded the province; although never needed, it had the necessary affect of maintaining zero tolerance of rats.

Demographics

Changes in land tenure patterns over the past five decades along the eastern border of Alberta has had a favorable impact on rat control. Continuous farmland consolidation and declining farmstead numbers (Figure 4) have resulted in decreased rat colonization due mainly to loss of rat habitat, even though rat control east of the province remained unchanged.

Agricultural Changes

Many technological and structural changes to prairie agronomy over the last 50 years, such as the "green revolution," specialization, diversified, and intensive livestock production have had a positive affect on rat control. The "mixed farm" of the 1950s became either a grain or livestock operation in the 1970s. In the process, many buildings, whether functional or obsolete were altered or removed, resulting in reduced rat habitat.

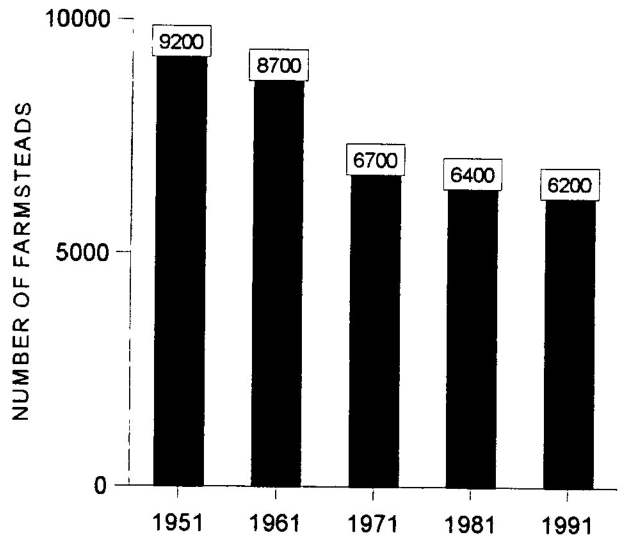

Figure 4. Number of farmsteads in eastern Alberta, 1951 to 1991.

Sanitation

Within the past three decades, traditional rural garbage disposal dumps or nuisance grounds have been replaced with more efficient and better supervised waste transfer sites (WTS). Provincial statute regulations for the management of refuse at WTS discourage or forbid practices deemed detrimental to the principles of today's concepts of "clean air" and "safe health."

Rat Proofing

The development of new and affordable building materials and designs has aided in controlling rats. For example, corrugate steel grain bins, hopper bottom bins, as well as metal silage towers, feed bunks, and reinforced concrete floorings have replaced wooden structures on many farms.

Careful management of feed and grain storage, such as proper spacing and placement of forage round bales, can deter rat inhabitation in storage yards.

Communications

Improvements to telephone and other communications systems between residents, municipalities, and PCOs have greatly enhanced rat control.

Adherence to basic on-farm strategies, such as keeping rat bait out at all times and consulting with PCOs when suspicious rodent activity is observed, have occurred as a result of the close relationship between landholders and PCOs.

Release of regular news media articles, including national television coverage, production of rat control publications, taxidermied displays, and hands-on training, have improved rat control awareness. In Alberta, citizens are encouraged and, indeed do, report suspect rat sightings, which is an enigma since most Albertans can not identify rats or rat sign. As a result, between 100 and 200 reported sightings are received and investigated annually, most turning out to be pocket gophers (*Thomomys talpoides*), muskrats (*Ondatra zibethicus*), Richardson's ground squirrels (*Spermophilus richardsonii*), or meadow voles (*Microtus* sp.).

Alberta has a world-wide reputation for being rat-free which brings writers, reporters, and media from around the world to witness the rat control program in action.

New Baits and Control Strategies

The development of new and more efficacious rat baits has dramatically improved rat control in Alberta. Inexpensive and versatile bait formulations, such as those designed with extended field life, high moisture resistance, and requiring only a single feed to cause death, are commonly used in Alberta. These baits have added features of safety, reliance, and diversity.

The rural nature of rat control in Alberta provides the unique opportunity to physically destroy rat colonies with fire, heavy equipment, fumigants, pyrotechnics, and firearms that may not be feasible or legal elsewhere. These control tools have been very useful, particularly where baiting has been problematic or where the window of control with conventional techniques is too short and immediate control action is required.

Attitude

The positive attitude of local residents, authorities and local politicians towards rat control has met with very little opposition. Rat control was, and still is, considered everyone's problem, therefore, everyone is expected to contribute accordingly. Generally, citizens are neither reluctant nor complacent participants. Also, despite occasional non-target poisoning accidents, neither controversy nor dispute has encumbered the good and successful conduct of the program. The program is managed by local citizens, free of government interference and, therefore, giving landowners and municipal leaders considerable independence to meet individual situations and conditions.

FUTURE OF RAT CONTROL IN ALBERTA

Eastern Border

So long as rats continue to invade from the east, Alberta will undoubtedly need to maintain the rat control zone strategy along the eastern border. Rat control vigilance should not be mitigated by the absence of rat infestations within the control zone nor by rat control conducted east of the Alberta-Saskatchewan border even by Alberta's PCOs.

Grain and livestock production have been the agricultural mainstay in eastern Alberta, and because there is very little likelihood of major change in these agricultural practices, rat control will likely continue to be important.

Until 1985, the only measurement of control was the total count of rat infestations. In actuality, this method only provided a relative index of control; a comparison of one year's success against another. However, due to the homogeneous nature of the municipal rat control strategy, a more accurate evaluation would be the combination of infestation size, lineal distance from the eastern border, and turn-around time (time from detection to clean-up); i.e., a "rat infestation index." Within the last five years, very few rat infestations were larger than 100 rats in size nor further than 11 miles from the border, with a turn around of time of less than 100 days.

Over the past 10 years, changes in infestation patterns indicate that rat control is approaching "ground zero" in many municipalities. Several municipalities have not reported a rat infestation in over a decade while the rest report a continual decline in infestations. At this rate, presumably no rat infestations will be found across the RCZ. How long a period of zero rat infestations will be necessary before the program will be changed, down-sized or discontinued, will no doubt be a political decision.

Interior

The Agricultural Pests Act forbids the importation, sale, or captive breeding of Norway rats or any subspecies or derivation of the genus *Rattus*. Pet shop owners, herpetologists, and other persons interested in keeping rats as pets are not allowed to do so in Alberta. Only hospitals, universities, and other related institutes of education, authorized by the government, are allowed to possess live *Rattus* species of any kind.

The occurrence of rats in the interior of the province, although not increasing significantly, is a growing concern for provincial authorities. Norway rats have been reported throughout the province and, not surprisingly, have been directly associated with the revitalized and emerging industrial boom that has taken place within the past three decades.

Added to this problem are the sophisticated and efficient transportation systems capable of delivering live rats across the continent in a matter of days. Further, overseas commerce via container shipping and rapid air freight around the world provides opportunities to import rats to Alberta.

The worst case scenario for rat control in the interior of the province would be undetected rat infestations on agricultural land. Due to the high number and density of farmsteads and the grain-livestock based agriculture within the province, rat control could be very difficult to achieve. To prevent such a disaster, the government relies heavily on the training and cooperation of government and municipal authorities in rat identification and control, open communications with the public, and an active rat control awareness campaign.

Fortunately, Alberta has a long reputation of being rat-free, so almost any person is able to contact the proper authorities to report a rat.

The Department of Agriculture has developed a rat response plan should rats be reported in the interior of the province. Incorporated in the plan are appropriate and necessary procedures and listings of resources including local, civic, and provincial authorities, as well as news media and other associated personnel whose involvement could be necessary to cope with a large infestation.

In retrospect, probably the single most critical point in the history of rat control in Alberta was the advanced thinking of provincial authorities some 45 years ago to take the bold initiative to halt the invasion of rats into the province. This is made more poignant when other provincial authorities at that time considered rats nothing more than a necessary risk to agriculture, much like weeds or grasshoppers, and were resigned to live with them. The future of rat control in Alberta looks very good, given the performance and support provided over the last 45 years, and more particularly the last decade.

ACKNOWLEDGMENTS

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CONTROL OF NORWAY RATS IN SEWER AND UTILITY SYSTEMS USING PULSED BAITING METHODS

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ABSTRACT: There were 1,288 sewer and 235 other utility manholes baited to control Norway rat (*Rattus norvegicus*) populations in downtown Boston using pulsed-baiting methods. About 15% of all sewer, 18% of phone, and 26% of electric manholes had rat activity. Sewer populations were most associated with residential areas with low flow, small diameter (<61 cm) brick sewers; in those circumstances, up to 38% of manholes had rat activity. Bait consumption in sewers (high risk areas) was 91% below baseline, five months after the fourth baiting period. Bait consumption and the number of active sewer holes were 96% and 87% below baseline, respectively, when seasonal maintenance baiting was last initiated. Reinfestation of phone/electric manholes was so minimal that maintenance baiting was not necessary or cost-effective. Subsurface baiting should be an integral part of urban rodent control programs.

KEY WORDS: sewer, pulsed baiting, utility system, integrated pest management, urban, Norway rat

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INTRODUCTION

Control programs for Norway rats (*Rattus norvegicus*) in urban areas characteristically are dominated by surface baiting and sanitation practices. Subsurface environments, such as sewer and other utility systems, commonly are not included when planning and implementing control measures. In part, this is because urban rodent control programs typically are reactive rather than proactive. A rat problem on the surface level is easily observable, and thus becomes the focus of pest control personnel rather than long-term strategies to manage rat populations.

Research on the ecology and control of Norway rats in sewer systems has been extremely limited in the U.S., particularly in the past 30 years. Work by Brooks (1962), Beck and Rodeheffer (1965), Barbehenn (1970), and Andrews and Belknap (1983) are examples of the limited literature available. Most information on rat control in sewers was generated by researchers in Great Britain, particularly during the 1950s and 1960s (Barnett and Bathard 1953; Bentley et al. 1955; Bentley et al. 1958; Bentley et al. 1959; Bentley 1960; Greaves et al. 1968). However, those investigations were prior to the paraffin bait formulations and active ingredients available today.

There are several reasons why there have been few studies of rat ecology and control in sewer systems and other underground utilities. These include logistics of traffic control, health and safety concerns, labor relations (union labor sometimes required to open manholes), street opening permits, and costs. These kinds of issues are not typical management concerns for field biologists.

As part of an $11 billion highway construction project in Boston, the downtown infrastructure and utility systems were extensively redesigned and construction undertaken for a new 8 to 10 lane underground highway (Colvin et al. 1990). This included relocation of 29 miles of utilities and installation of new utilities to replace numerous layers of overlapping and aging systems ranging from sewers, to phone and electric systems, cable tv, and steam and gas lines. This effort required a subsurface baiting program to eliminate rat populations prior to excavation, and concurrent control in adjoining neighborhoods to limit reinfestation of the project alignment. The purpose of this paper is to describe the baiting methods that evolved, control achieved, and recommendations for subsurface baiting programs.

RATS AND UTILITY SYSTEMS

Norway rats use sewer systems for feeding, movement, and living space. They may create burrows and excavations at cracks or breaks in sewer lines where there is soil settlement or structural movements around the pipe, pipe aging or corrosion, invasion by tree roots, or structural flaws in the system. Burrows can lead to surface level or through the foundation wall of a nearby building. Rats also can enter buildings through an open service hole in a sewer pipe inside a basement or through a toilet (usually basement or first floor). Localized accumulation of soil inside a sewer, because of rat excavations or infiltration from outside the system, also can provide a medium for burrows.

A sewer can be a combined system (storm water and sanitary flows in the same pipe) or have the storm drains and sanitary lines separate. Sanitary or combined systems have greater risk of rat activity than storm drains because of better availability of food within them. The trend towards separated storm and sanitary lines began in the 1950s because of limitations in sewage treatment capacity and water pollution from direct discharges to water bodies.

Brick was the most commonly used material to construct sewers in the early 1880s to mid 1900s; iron and wood also were used historically. However, most sewers installed in the past 50 years in the U.S. have been vitrified clay or pre-cast concrete; the use of PVC (polyvinyl chloride) became popular in the late 1980s. Because brick sewers can lose mortar and bricks, and clay pipe typically is installed in 4 to 5 foot sections, gaps for rat burrowing can occur most with those materials, especially over time.

Catch basins that provide street-level drainage can become infested or provide access into and out of a sewer system. Excessive debris or soil inside a catch basin can serve as a base for burrowing. Structural problems, such as missing bricks or cracks, provide gaps for burrows and access underneath sidewalks or into adjacent buildings through cracks in foundations.

Other types of underground systems that can be inhabited by Norway rats include phone, electric, and cable tv manholes and their ducts. Rats can live inside them and use the ducts (typically 10 cm diameter) to travel between manholes. Ducts may contain cable or be unoccupied spares. If not plugged at the building end, they can be used as access routes into basements for feeding. If structural flaws exist in a utility manhole, rats may move through excavations to surface levels. It also is feasible that rats can move between sewer and phone/electric systems underground through structural cracks in adjoining systems, particularly where utility systems are densely situated.

Rats can create or enhance structural problems in manholes and sewer lines through their excavations and gnawing. They are capable of damaging underground cable by gnawing on them (although the authors found that to be uncommon in Boston). Sudden encounter of rats by utility personnel working in a manhole creates a work environment issue. Additionally, rat-borne diseases, such as leptospirosis, are believed to be a particular concern in wet rat-infested environments and have been identified with the need for sewer baiting programs (Howard 1989).

BACKGROUND STUDIES

Preliminary to this program, manhole baiting was performed for another construction project in Charlestown, Massachusetts (Colvin et al. 1990). Baiting methods, bait formulations, and distribution of rats in sanitary and storm drains were assessed in a residential area. Sanitary sewers were 2.7 times more active than storm sewers based on bait consumption. Forty-two percent of sanitary sewer manholes and 23% of storm drain manholes had rat activity. Rats were effectively controlled by pulsed baiting with 60 g of bait (50 ppm brodifacoum, TALON Weather Blok) in storm sewers and with 100 g of bait in sanitary sewers.

Other preliminary work included live-trapping rats using Tomahawk traps (13 x 13 x 41 cm) in downtown Boston manholes during the last two weeks of October 1992 to help plan the control program and collect rats for genetic resistance testing. Traps were lowered into 74 manholes (combined sewer system; brick) using an extendable pole and attached by wire to a nail driven into the top of the manhole chimney; traps were baited and wired open for 5 to 6 days prior to live trapping. Average pipe width was 42 cm (range 20 to 76 cm); 95% were less than 51 cm.

Forty-three rats (56% juveniles) were captured; trap success was 14.7% the first night and 12.5% four nights later. Rats were not randomly distributed; 72% were trapped in 6.7% of the holes surveyed (captures were made in 20% of the holes). The presence or absence of droppings was not a good predictor of trap success, and the most active holes had small diameter pipes with low flows in residential areas. Twenty-two of the rats (4 male, 18 female) were tested by BioCenotics, Osseo, Michigan, using the WHO protocol for warfarin resistance; 13.6% (3 females) survived testing. Among 45 rats (21 male, 24 female) collected from surface areas in Boston during fall 1992, 17.8% (2 male, 6 female) were resistant. No sewer baiting programs had been conducted previously in Boston and, thus, presence of resistance in the sewer population indicated rat movement between surface and subsurface environments.

METHODS

Areas to be sewer baited were investigated using drainage maps provided by the Water and Sewer Commission. Maps identified sewer type (storm, sanitary, combined), diameters and materials, ages, and manhole locations, so that field operations could be effectively planned and tracked. Utility maps also were used to identify other manholes to be baited (phone, electric, cable tv). Data sheets were used in the field to record hole numbers, bait placed, bait consumed, water volumes in holes (none, low, moderate, high), and general observations each time a hole was opened. All accessible manholes were baited, except for those with substantial water volumes and flows (typically sewers >91 cm diameter). Baiting locations were mapped and tracked using a geographic information system (vonWahlde and Colvin 1994).

All manhole baiting was done from surface level with a two-person pest control crew assisted by a police officer (required for traffic control). All phone, electric and cable tv holes were opened by personnel from utility companies because of union and safety requirements. For more intensely baited areas, a project biologist accompanied the crew to confirm accurate mapping and record keeping, and as oversight since the work was paid on an hourly basis. Safety precautions included reflective traffic vests, knee pads, latex gloves for the baiter, and work gloves for the person pulling the manhole covers.

Manholes were tagged and each uniquely numbered using a 3 cm diameter aluminum tag (available from Forestry Suppliers, Inc., Jackson, Mississipppi). Plastic coated, galvanized, 24 gauge wire (made by Anchor Wire Corp., Goodlettsville, Tennessee) was used to suspend the bait; the plastic coating was necessary to slow corrosion of the wire and allowed for gnaw marks to be discerned to help confirm rat activity. A masonry nail was driven into the mortar or concrete at the top of each manhole, bait was attached to the end of the baiting wire and lowered to within 2 to 5 cm of the benching in the manhole base, and the wire was cut from the spool and wound around the nail so that a 15 cm piece extended from it; the numbered tag was then attached to that end of the wire. For subsequent baitings, wire loops of bait often were made in advance to facilitate field operations. The bait wire in a hole could be pulled up, the existing bait loop cut and removed to a spoil bucket, and a new loop of bait wired on and lowered back down. Orange spray paint was used to mark the street next to baited holes, to aid locating them.

Baiting was performed seasonally using pulsed-baiting methods (Dubock 1992), in a geographically sequential process beginning in 1992, matching construction staging. The baiting formula typically was day 1-14-28, indicating approximately two weeks between baiting rounds (pulses). Five TALON Weather Bloks (brodifacoum, 50 ppm, 20 g block) were used for each baiting round. In a few cases when all bait was consumed in a manhole on the first round, during the initial baiting of a new area, the bait placement was doubled from 100 to 200 g for the next round. Thereafter, and for all maintenance baiting, five bait blocks (100 g) were used each baiting round.

Activity was based on bait consumed, visually measured to 1/4 block. Gnaw marks on bait or the baiting wire were identified as rat activity. Bait with a peppered coarse appearance was recorded as cockroach (insect) activity. A wire with the bait loop void of bait, yet still in a rectangular shape as if blocks were present, was recorded as insect or water damage, depending upon insect observations and water/steam conditions. An empty bait loop stretched in an elongated manner was identified as water/debris damage, or rat activity if gnaw marks could be found.

Spring (March/April) and fall (August/September) baiting was performed for all sewers. An early summer (June) and late fall (November) baiting also was implemented in 1997 in neighborhoods where potential reinfestation and construction were greatest. Other utilities were baited independent of season. Most holes that never had activity were eliminated after a year; maintenance baiting consisted of once-active holes and a few sentinel baiting points where construction operations required it.

RESULTS

There were 1,288 sewer manholes poison baited among eight contiguous geographic sections of the project alignment (Table 1). Only one area had a separated sewer system (Area 3); others had predominately combined systems. In addition to the sewers, 235 other utility manholes (120 phone, 90 electric, 25 cable tv) were baited among Areas 4, 6 and 7. In total, 15.1% of sewer, 17.5% of phone, 25.6% of electric, and 8% of cable tv manholes had bait consumption.

Sewer activity was highly variable among the eight areas, ranging from no activity to 38% activity among manholes baited. Areas with little or no activity included predominately commercial locations (Areas 2, 5, 6, 8) and sewers built mainly with clay or concrete (Areas 2, 5, 8). Locations with high activity (Areas 1, 3, 4) predominately were residential with old brick sewers.

Bait consumption ceased each season within three rounds during initial baitings and typically within two rounds during maintenance baiting. Rat activity in sewers was 91.3% below baseline (8.7% recovery from baseline) about five months after the fourth baiting season (Figure 1), and the number of active holes had declined from 98 to 16. (That level of sustained reduction likely would have occurred much sooner if the entire system had been treated at once, rather than sequentially to match construction staging.) When the program was fully in maintenance throughout the sewer system (fall 1997), seasonal bait consumption was 96.2% below baseline, and only 13% of the holes originally active showed sign of reinfestation (Areas 4 to 7). In the oldest brick system (Area 4), the percent of manholes active declined from 33% (baseline) to 4% (maintenance).

Rat activity was more widely distributed in electric than phone manholes, but phone manholes had greater concentrations of activity (initial bait consumption 17.7 g and 34.1 g per manhole, electric and phone, respectively). Activity rapidly declined after one baiting period (Figure 2). Reinfestation was almost negligible in both systems, using annual intervals between baitings. By the third and fourth baiting periods, consumption was 97.1% and 93.8% below baseline for phone and electric, respectively.

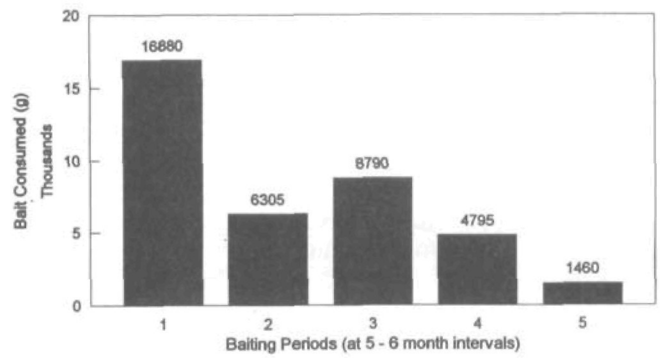

Figure 1. Changes in sewer rat activity from baseline, based on bait consumption. Baiting period 1 represents the first time that each manhole was baited, independent of season and year. Each baiting period consisted of baiting rounds at 14-day intervals until activity ceased.

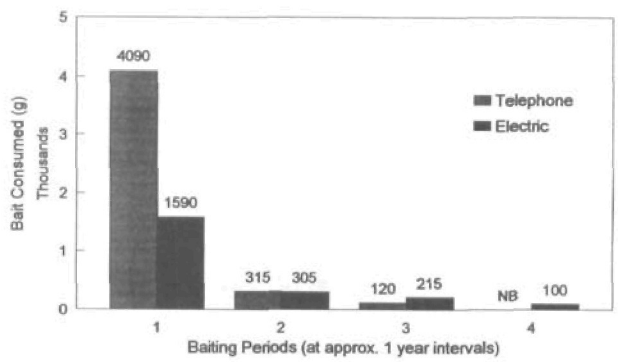

Figure 2. Changes in rat activity in phone and electric manholes, based on bait consumption. Baiting period 1 represents the first time each hole was baited, independent of season and year. Each baiting period consisted of baiting rounds at 14-day intervals until activity ceased.

Table 1. Results of sewer manhole baiting for Norway rat control in Boston, 1992 to 1997.

Area	No. Manholes Active	Inactive	System Approx. Age	Dominant Material	Environment
1-E. Boston	38 (32%)	79	1852-1916	Brick	Residential
2-S. Boston	6 (6%)	94	1916-1937	Clay	Commercial/Industrial
3-Charlestown*	27 (38%)	45	1850-1903	Brick	Residential
4-North End	74 (33%)	148	1824-1915	Brick	Residential/Commercial
5-Leverett Crl./Govt. Ctr.	2 (1%)	146	1914-1980	Clay	Commercial/Residential
6-Financial Dstr.	22 (8%)	264	1850-1906	Brick	Commercial
7-Chinatown	25 (15%)	142	1852-1916	Brick	Commercial/Residential
8-South End	0	176	1861-1957	Clay, Brick	Commercial/Residential
TOTALS	194	1,094			

*Predominately separated sewers; other areas predominately had combined sewer systems.

The amount of bait consumed and the number of active sewer manholes steadily declined during maintenance baiting and varied seasonally. The fall period showed the greatest amount of bait consumed per manhole and percent of manholes active (Figure 3). For example in fall 1994 (Areas 4 to 7), there were 68.6 g of bait consumed per manhole, and 46% of the manholes being treated were active; whereas in fall 1997 there were only 1.8 g of bait consumed per hole (97.4% less than fall 1994) and 5% of the holes active. The 1997 fall reduction was in part achieved by instituting summer baiting of selective holes as part of the maintenance program.

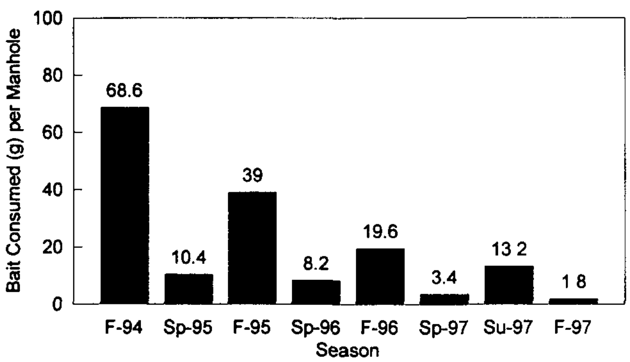

Figure 3. Changes in sewer rat activity by season, based on bait consumption.

The time interval from fall to spring consistently had less population recovery in sewers than the spring to fall interval (Figure 3). These seasonal differences suggest that rat breeding was not uniform year round, as might be expected given that sewers provide warmth and continual food availability, and relatively consistent light conditions.

Rat activity among sewers was highly non-random, considering either flow rates (Chi-square=62, 3 d.f., $P<0.001$) or pipe sizes (Chi-square=18.5, 5 d.f., $P<0.01$). Within a sample of 1,095 baited holes, flow rates were distributed as: 24% no flow, 59% low flow, 14% moderate flow, and 3% high flow. Of the holes with rat activity, 90% had low flow and 10% had moderate flow.

Pipe widths of baited manholes (Areas 4 to 7) ranged from 20 to 259 cm (mean=54.2 cm; n=723). Those with rat activity ranged from 20 to 244 cm (mean=43.9 cm; n=118), and those without activity ranged from 20 to 259 cm (mean=57.9; n=605). The percentage of manholes active was greatest among those with 51 cm pipes (31%); 90% of the active manholes had 20 to 61 cm pipes.

Observations of live or dead rats were rare. Observations of droppings were uncommon, even in manholes where bait was consumed. American cockroaches (*Periplaneta americana*) were widely, but not evenly, distributed among both sewer and utility manholes. Roaches demonstrated an ability to consume an entire bait placement, thus requiring close examination of baiting results to distinguish roach from rat activity. Fluctuating water levels and steam also eliminated bait, requiring close examination of baiting wire to prevent misidentification as bait consumption.

Baiting costs per hour were approximately $77 for a two-person baiting crew, $29 for a police detail, and $45 for a project biologist. The number of sewer holes baited per hour was approximately ten for initial placements and 15 for maintenance baiting. Costs for baiting phone manholes included two crafts personnel and a supervisor from the utility to open the holes; those costs were about $370 per hour with administrative overhead, and about ten manholes could be baited per hour. Lower utility costs per hour eventually were achieved when utilities provided one crafts-person to open holes.

DISCUSSION

The goal and methods for sewer control programs are somewhat different from that of surface programs. The intent with sewer baiting is to dramatically and cost-effectively suppress a rat population through poison baiting. Unlike surface areas where IPM principles can be fully implemented with a strong emphasis on sanitation, the nature of a sewer is that sanitation and water resources will remain available and unchanged throughout the control program. Thus, the expectation should be to effectively manage the population and not necessarily to totally eradicate it.

Random, haphazard, or reactive sewer baiting does little to actually manage a rat population or to solve localized problems. Subsurface baiting requires a systematic approach with close review and adjustments of the baiting strategy based on the quantities and geographic patterns of bait consumption. This takes time to plan, but allows for field implementation to be strategic and thus more cost effective.

The number of seasonal baiting periods performed annually should be based on the level of control necessary and the extent of the existing infestation. Where systems are infested, it is recommended that the initial program consist of three baiting periods the first year (e.g., March, June, September) to effectively dampen the population and slow the recovery rate. (Each baiting period would consist of baiting rounds at 14-day intervals until activity ceases.) Inactive holes should be culled from the program at the end of the second baiting period (season), except for a few sentinel holes maintained in locations of potential future risk (e.g., near restaurants, residences). Thereafter, the baiting regimen should be customized annually, centers of activity targeted, and holes prioritized based on baiting histories (Forbes 1990). The seasonal timing chosen was intended to eliminate adults prior to onset of peak periods of parturition or weaning, further slowing recovery rates.

A maintenance program could include the following: March/April and August/September—pulse bait all holes that once were active, and possibly a strategic/limited number of sentinel holes, until activity ceases. For high risk areas where heightened control is desired, also pulse bait in June and November, but only those holes active the previous season. Over time, holes never active can be culled or periodically treated on a sentinel basis. In this work area, the number of sewer manholes baited was reduced from 1,288 to less than 225 necessary to maintain monitoring and control (>90% reduction in rat activity over baseline at all times). The maintenance budget, for a two-person baiting crew, concurrently was reduced to <$10,000 per year for a five square mile area.

Recovery of sewer populations is likely within six months (or less) if they are not effectively baited (Bentley et al. 1959; Brooks 1964). Baiting programs that use single bait placements (e.g., annual or twice annual), without follow up, simply crop a portion of the population and enhance the rate of population growth. Key to an effective sewer program is to reduce the population to minimal levels (e.g., >90%), so that it remains at the low end of the sigmoidal growth curve until the next baiting period; otherwise recovery will be rapid and little achieved. The benefit of pulsed baiting is that it can dramatically lower a subsurface population, best ensuring a slow rate of population recovery.

Pulsed baiting is especially important in sewers because of their dynamic nature (loss of bait from changing water levels, steam, roaches). Repeated baitings and checks over a short period of time (e.g., six weeks) help ensure delivery of bait to the population and determination of necessary baiting points. Otherwise, baiting continues to be random and costly, and animals may be "over killed" by use of excessive amounts of bait. Importantly, the pulsed strategy allows time between baiting rounds for rats living between manholes to redistribute, expand their tubular territories, and thus encounter bait placements.

The effectiveness of a control program and the needed intensity of baiting can be determined by calculating the rate of recovery each baiting period. If control has been broadly achieved in the system, the rate of reinfestation will be low. Data from this study indicate that broad control was achieved over the entire sewer system by strategically pulse baiting.

Sewers greatly differed from other utilities in their ability to sustain rat populations. The lack of population recovery and reinfestation of phone/electric manholes indicated that those systems held relatively closed populations with limited food resources. Control programs for such utilities do not appear to require much on-going maintenance once control is achieved.

Environmental factors such as excessive availability of food and harborage have been associated with development of genetic resistance to some anticoagulant rodenticides (Jackson and Ashton 1992; Greaves 1994). Thus, sewer environments should be considered ideal for nurturing resistant strains of rats and potentially could enhance spread of genetic resistance in an urban area if baited inappropriately. For these reasons, as well as efficacy and labor costs, the authors do not recommend the use of first-generation anticoagulants or saturation baiting in sewers. The second-generation material selected should not have documented resistance problems.

The kind of bait that is recommended for sewers would be a single-feeding, highly palatable, paraffin block formulation. The block would have homogeneously distributed ground grain, rather than whole seed or cracked grain. The latter type of formulation appears to absorb moisture and deteriorate more quickly. The recommended size for a bait block (second generation anticoagulant, e.g., brodifacoum) would be about 100 to 125 g, with one block used each baiting round in a pulsed-baiting strategy. Larger blocks of second-generation anticoagulant bait (e.g., 450 g) appear unnecessary and wasteful.

Subsurface populations can serve as a reservoir to potentially infest surface areas or adjacent buildings, and surface populations may retract into sewers, especially with the onset of winter in middle-latitude climates. These factors are important when evaluating localized rat infestations on surface levels and timing control efforts. It was found that the presence of a rat population on the surface level does not necessarily mean that rat activity exists in the sewer system below. However, where surface problems are present or chronic, sewers should be test baited.

Several factors appear to contribute to rat infestations in sewers. Sections of combined or sanitary systems with low flow and small diameters (< 61 cm) built with brick were most susceptible in the work area (Figure 4). Land use most commonly was residential or mixed residential/commercial (restaurants) where activity was found, and the brick sewers were 85 to 175 years old. Better feeding opportunities for rats exist with low flows because solids tend to drop out of the water column. Small diameter lines also are more stable for rat survival because of less flooding. Brick sewers potentially provide more gaps for living space than concrete or clay lines.

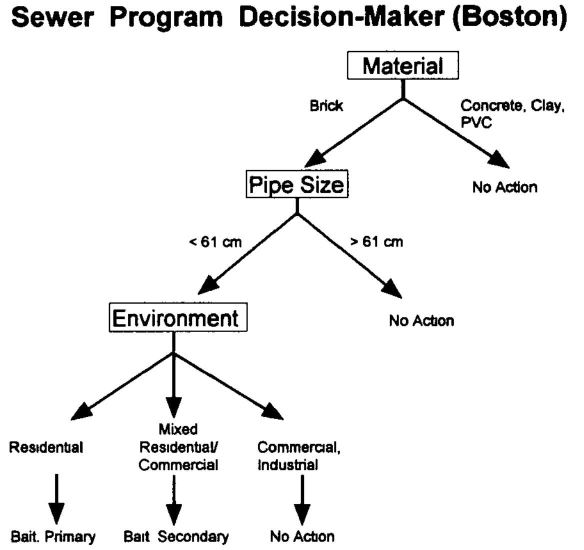

Figure 4. Decision-making flow chart for planning and prioritizing a sewer baiting program.

Topography may also influence rat distribution patterns. Within the sewer collection system for Areas 4, 6, 7 and 8, Area 4 was the highest point and Area 8 was the lowest. Potential flooding of the system during rainfall events, as a result of topographic differences, possibly could have contributed to the lack of rat activity in Area 8. Additionally, utility (phone/electric) workers that were interviewed described shifts in rat activity from manholes near the waterfront to those at higher elevations, during flooding or high tide events.

Engineers should consider the Norway rat to be an indicator species, helping to determine sewer locations in need of structural evaluation and priority for repair. Baiting results and maps should be discussed with the local Water and Sewer Authority, and major centers of rat activity can be inspected by the Authority using remote cameras. This process may identify locations that need to be flushed or cleaned to remove a build-up of sediment/ soil used by rats for burrowing or, more commonly, locations in need of repair. Smoke tests also can be used in sewers to evaluate breaks leading into basements or to surface level.

Good inspection, maintenance, and installation of a sewer system are important for limiting rat populations from inhabiting them. Several methods are used today for sewer rehabilitation including pipe replacement with cut and cover trenching methods, filling the existing system with grout and micro-tunneling, installing a pipe liner using pipe bursting technology, or using a cured-in-place plastic-resin lining.

Many myths exist about rats in sewers, from unconquerable numbers to blind populations, contributing to inappropriate control methods and mis-education of the public. Myths also have included assumptions that any construction or vibration near a sewer line will cause rats to flee the system. Barnett and Bathard (1953) observed that rats will continue to inhabit sewers while they are under construction, and the authors believe, based on observations, that direct excavation is necessary to cause displacement. In fact, rats will readily inhabit cut-and-cover trench excavations during utility construction.

Subsurface control programs should be an integral component of any Integrated Pest Management (IPM) program in urban environments. However, many municipalities and pest control operators in the U.S. are unfamiliar with, or poorly understand, sewer baiting principles and needs. Sewers can be viewed by pest control personnel as undesirable work environments, logistically difficult to access, an unknown best left alone, or potentially expensive to treat. These factors illustrate the need for a cultural change in many urban pest control programs that only will occur through training and experience.

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RECENT NORWAY RATS STUDIES USING WARFARIN

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ABSTRACT: Warfarin resistance in the Norway rat (*Rattus norvegicus*) has been studied over the past 30 years. To determine the status of this resistance phenomenon wild Norway rats were collected from Colorado and Chicago, Illinois. As reported previously, warfarin resistance in the Chicago area exceeds 50%, while rats from Colorado remain very susceptible to warfarin. The theory that true genetic resistance may not exist was examined, implying that geographic variation in intestinal flora contribute to the rapid degradation of warfarin after ingestion, along with production of sufficient Vitamin K in the bacteria to reverse the effect of warfarin. Antibiotics in combination were tested with warfarin and demonstrated that efficacy in the laboratory can be increased by using the combination in a bait form.

KEY WORDS: warfarin resistance, Norway rat, potentiation, antibiotics, efficacy, bacteria

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INTRODUCTION

The anticoagulant rodenticide warfarin was developed during the 1940s and quickly took hold as an effective means of rodent control and replaced many of the more toxic and acute compounds. By 1958, Boyle (1969) reported Norway rats (*Rattus norvegicus*) developed resistance to warfarin on farms in Scotland. Reports surfaced within the next 20 years from various parts of the globe indicating that the compound was losing its effectiveness. Such genetic resistance was reported from the United States by Jackson and Kaukeinen (1972).

As a result of these increasing reports of Norway rats' resistance, more potent second generation anti-coagulants were developed to overcome the perceived resistance problems. These newer rodenticide products contained such compounds as brodifacoum, bromadiolone, difenacoum, flocoumafen, and difethialone.

During 1995 wild Norway rats were collected from Chicago and Colorado. These were subjected to the routine World Health Organization (WHO) screening test for warfarin resistance (WHO 1982). The purpose of this study was to determine if Norway rats in the Chicago area, previously documented as warfarin resistant, remained resistant to warfarin after the extensive use of second generation anticoagulants. Although cross resistance has been reported from various parts of the globe, an objective was to determine if resistance remained in Chicago. It was during that time that the search for other mechanisms involved in warfarin resistance in rats began. Why was there a perceived failure of warfarin as a rodenticide? Although Chicago and Colorado, or Iowa and Colorado, are not geographically separated, the consideration of what other mechanism might be involved in the reduced toxicity of warfarin based on geography remained in question.

Consideration to drug potentiation, or the interaction of warfarin with other compounds was examined from the literature. Previous studies have demonstrated the potentiation of non-steroid anti-inflammatory drugs on warfarin (Sirdhara and Krishnamurthy 1992). As early as 1974 Lewis et al. (1974) found that phenylbutazone potentiated anticoagulant effects.

METHODS

Wild Norway rats were trapped using Tomahawk live traps. Rat infested areas of Chicago suburbs and feedlots in eastern Colorado were the source of wild rats used in this study. The areas selected in Chicago had not been recently baited by the Bureau of Rodent Control. Likewise, trap sites utilized in Colorado did not have recent rodent control efforts. Traps were placed in and around garages, along building walls, and vacant lots and were baited with a grain bait. Traps were monitored each morning. In Chicago, trapped animals were brought to the nearby regional office of the Bureau of Rodent Control warehouse, dusted with an EPA approved flea powder and placed in cages individually until transport back to the Genesis Laboratories facility in Colorado. Rats were trapped between April 1995 and October 1997. Rats were acclimated from two to six weeks before testing. The temperature within the test room was maintained at approximately 20 to 25°C and a photoperiod of 12 hours light:12 dark was maintained for the duration of the test. The average humidity was maintained between 25 to 55%.

Liquid Provision of Tetracycline

The WHO testing protocol for warfarin resistance in Norway rats was used for screening rats in 1995. Subsequently, since resistance was approximately 50%, additional rats in 1996 and 1997 were trapped for further study. Treatment and control groups were established. Control groups received 50 ppm warfarin-treated cracked corn for six consecutive days in a no-choice test. Separate treatment groups of rats were presented with 5 and 20 mg tetracycline per ml of water *ad libitum* for three days before presentation of the 50 ppm warfarin bait. A separate group was given one 750 mg/kg dose of tetracycline hydrochloride via oral gavage three days before presentation of the warfarin bait. After obtaining interesting results in 1996, grain bait were formulated incorporating antibiotics.

Preparation of Antibiotic Baits

The 0.005% warfarin bait was prepared using a Hobart Mixer. Cracked corn was used as the carrier.

An appropriate solvent was used to facilitate proper mixing of the warfarin in the mix. Baits were prepared containing of 0.005% warfarin and either tetracycline or metronidazole at various concentrations.

There were three treatment groups of Norway rats: warfarin control, warfarin with tetracycline, and warfarin with metronidazole. A treatment group consisted of eight Norway rats (four males and four females). Three replications of each level were subjected to the experimental design.

The treated baits were offered on six consecutive days. Each cup contained 40 grams and consumption was weighed every 24 hours. Consumption was recorded and additional feed was added so each cup contained 40 grams. At the end of the six-day test period, the test material was removed and Manna Pro Lab Cubes were provided *ad libitum* during the ten-day post-test observation period.

Observations were recorded twice daily during the exposure and post-treatment periods. Signs of warfarin intoxication and mortality were recorded, as well as bait consumption.

RESULTS AND DISCUSSION

Representative results of the Norway rat warfarin screening for animals collected from Colorado and Chicago are presented in Tables 1 through 4. During 1995, 187 (144 males and 43 females) rats were trapped from Chicago and screened for warfarin resistance. Of these, 55% survived the 50 ppm warfarin diet presented for six consecutive days.

Fifty-three Norway rats collected from Colorado were examined for warfarin resistance. All rats died after the six-day exposure. These data support previous claims that the Chicago Norway rat population was genetically resistant to warfarin while rats from Colorado were non-resistant.

Norway rats given tetracycline-treated water for three days before presentation of 50 ppm warfarin diet were more susceptible to the bait (Table 5). Mortality in the control groups, those rats fed 50 ppm warfarin without the antibiotic, averaged 54.3%; while the treated groups receiving 5 and 20 mg per ml, respectively, attained 90% mortality.

The group of rats gavaged once with 750 mg/ml tetracycline then exposed to a 50 ppm warfarin diet did not respond in a similar manner. Mortality was only 60%, indicating that repeated doses were more efficacious in depleting the intestinal flora.

During 1997, additional research was conducted on tetracycline and metronidazole treated (Borchert 1997). A summary table of that study is presented in Table 6. Test groups treated with warfarin control, warfarin plus tetracycline, and warfarin with metronidazole additive, resulted in mortality of 74.1, 92.6, and 92.6%, respectively. There was no significant difference in consumption for the three formulations tested.

The results of adding certain antibiotics to warfarin indicate that efficacy can be enhanced when controlling Norway rats. Test groups exposed to 50 ppm warfarin including an antibiotic achieved high mortality. In the past, the nominal concentration of most warfarin baits sold in the U.S. was 250 ppm, more than adequate a concentration to attain effective Norway rat control.

Drug interactions with warfarin have been reported previously and the number of compounds that potentiate the effects are numerous (Wells et al. 1994). The exact mechanisms involved, however, remain nebulous.

The addition of tetracycline and metronidazole, as well as other antibiotics to warfarin, increases the toxicity over warfarin alone and is attributed the bacteria in the intestinal tract. Although previous studies indicated that earlier forms of antibiotics did not appreciably affect the efficacy of warfarin (Derse 1963), newer and stronger antibiotics are more efficacious in eliminating gut bacteria. It is felt that the mechanism in this case involves the action of the antibiotic on the intestinal flora of the Norway rat. Geographic variation within species and number of bacteria results in differing impact on the reaction to chemicals entering the gastrointestinal tract of the rat, and possibly the mouse. Warfarin is a relatively unstable compound and degrades into less toxic metabolites. The half-life in the gastro-intestinal tract is a mere 42 hours (Ford 1993). Dupont (1996) reported the effective half-life of approximately 40 hours. About 92% of the parent compound is excreted in the urine with a small percentage being the parent material.

Once reaching the gut of the rat, warfarin bait begins to degrade, based on the types of bacteria present. The degradation rate in areas such as Chicago influences the amount of parent compound available for absorption into the rodent system.

Warfarin elimination is almost entirely by metabolism by hepatic microsomal enzymes to inactive hydroxyiated metabolites by reductases to reduce metabolites (warfarin alcohols). The warfarin alcohols have minimal anticoagulant activity (DuPont 1996). The metabolites are principally excreted into the urine and to a lesser extent into the bile. The metabolites of warfarin have identified and include dehydrowarfarin, two diastereoisomer alcohols: 4'-, 6-, 7-, 8-, and 10-hydroxywarfarin.

Bacteria capable of producing more vitamin K, the antidote for warfarin, also contributes to the reduced toxicity of warfarin in certain populations of Norway rats. It is suggested that a combination of factors involving the degradation of warfarin by bacteria and the production of vitamin K by the intestinal flora contribute to reduced toxicity of the rodenticide. This geographic variation in the ability of Norway rats to tolerate warfarin, is probably attributed to regional differences in intestinal flora species. The issue of Norway rat genetic resistance to warfarin in the U.S. requires careful re-examination again, especially in light of the regulatory restrictions being placed on more toxic anticoagulants.

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Table 1. Results of warfarin resistance screening test for Norway rats collected in Colorado during 1995.

Animal No.	Sex	Body Wt. (g)	Warfarin Consumption (g)	Consumption/kg Body Weight (g)	Mortality
CO-101	F	277	73.5	265.3	Yes
CO-102	F	251	77.5	308.8	Yes
CO-103	F	187	110.7	592.0	Yes
CO-104	F	204	115.7	567.2	Yes
CO-106	F	190	86.0	452.6	Yes
CO-107	F	180	67.3	373.9	Yes
CO-108	F	234	78.8	336.8	Yes
CO-109	F	204	73.5	360.3	Yes
CO-110	F	277	110.7	399.6	Yes
CO-111	F	207	91.0	439.6	Yes
CO-112	F	180	84.7	470.6	Yes
CO-113	F	283	105.2	371.7	Yes
CO-114	F	208	109.2	524.0	Yes
CO-115	F	201	84.4	419.9	Yes
CO-116	F	198	93.5	472.2	Yes
CO-117	F	200	95.6	478.0	Yes
CO-118	F	189	76.2	403.2	Yes
CO-119	F	223	81.2	364.1	Yes
CO-120	F	196	80.9	412.8	Yes
CO-121	F	266	135.0	507.5	Yes
CO-122	F	268	120.2	448.5	Yes
CO-124	F	192	84.9	442.2	Yes
CO-126	F	236	86.4	366.1	Yes
CO-127	F	245	92.4	377.1	Yes
CO-128	F	217	113.7	524.0	Yes
CO-129	F	291	90.5	311.0	Yes
CO-130	F	264	116.0	439.4	Yes
CO-131	F	294	70.9	241.2	Yes
CO-132	F	297	74.0	249.2	Yes

Table 2. Results of warfarin resistance screening test for Norway rats collected in Colorado during 1995.

Animal No.	Sex	Body Wt. (g)	Warfarin Consumption (g)	Consumption/kg Body Weight (g)	Mortality
CO-1	M	358	75.5	210.9	Yes
CO-2	M	326	76.5	234.7	Yes
CO-4	M	346	102.2	294.8	Yes
CO-5	M	278	80.8	290.6	Yes
CO-6	M	316	80.3	254.1	Yes
CO-7	M	394	90.7	230.2	Yes
CO-8	M	331	81.6	246.5	Yes
CO-9	M	223	95.6	428.7	Yes
CO-10	M	355	113.9	320.8	Yes
CO-11	M	323	93.6	289.8	Yes
CO-12	M	333	122.8	368.8	Yes
CO-13	M	310	12.7	41.0	Yes
CO-14	M	277	37.3	134.7	Yes
CO-15	M	325	85.0	261.5	Yes
CO-16	M	272	88.0	323.5	Yes
CO-17	M	357	82.4	230.8	Yes
CO-18	M	450	115.7	257.1	Yes
CO-19	M	325	104.1	320.3	Yes
CO-20	M	280	95.6	341.4	Yes
CO-21	M	322	84.0	260.9	Yes
CO-22	M	262	55.8	213.0	Yes
CO-23	M	373	131.1	351.5	Yes
CO-24	M	313	82.9	264.9	Yes
CO-25	M	171	72.0	421.1	Yes

Table 3. Results of warfarin resistance screening test for Norway rats collected in Chicago during 1995.

Animal No.	Sex	Body Wt. (g)	Consumption/Kg Body Wt. (g)	Mortality
IL-33	M	389	164.3	Yes
IL-34	M	369	313.8	Yes
IL-35	M	319	149.5	Yes
IL-36	M	400	42.0	No
IL-37	M	434	206.0	No
IL-38	M	393	230.5	No
IL-39	M	413	138.0	No
IL-40	M	358	169.3	No
IL-41	M	309	250.8	Yes
IL-42	M	399	105.8	Yes
IL-43	M	388	229.4	No
IL-45	M	367	220.7	Yes
IL-46	M	467	177.9	Yes
IL-47	M	378	222.5	Yes
IL-48	M	276	285.5	Yes
IL-49	M	449	143.2	Yes
IL-50	M	472	152.5	Yes
IL-51	M	255	239.6	No
IL-52	M	356	294.4	No
IL-53	M	227	291.2	No
IL-55	M	392	79.8	Yes
IL-56	M	478	193.7	No
IL-57	M	357	148.5	No
IL-59	M	348	136.2	Yes
IL-60	M	463	259.8	Yes
IL-61	M	393	169.7	Yes
IL-62	M	361	265.9	No
IL-63	M	415	121.7	No
IL-64	M	297	88.2	Yes
IL-65	M	425	152.7	Yes

Table 4. Results of warfarin resistance screening test for Norway rats collected in Chicago during 1995.

Animal No.	Sex	Body Wt. (g)	Consumption/Kg Body Wt. (g)	Mortality
IL-131	F	294	325.5	No
IL-132	F	349	50.1	Yes
IL-133	F	178	286.5	Yes
IL-135	F	228	307.0	Yes
IL-137	F	282	74.8	Yes
IL-138	F	263	238.0	Yes
IL-139	F	206	243.7	Yes
IL-140	F	317	263.4	Yes
IL-141	F	418	177.0	Yes
IL-142	F	250	457.6	Yes
IL-143	F	300	371.7	Yes
IL-144	F	305	251.1	No
IL-145	F	292	440.4	No
IL-146	F	292	337.7	No
IL-147	F	368	270.4	No
IL-148	F	350	242.3	Yes
IL-150	F	286	147.2	Yes
IL-151	F	322	329.8	No
IL-152	F	335	253.4	No
IL-153	F	347	276.4	No
IL-154	F	195	275.9	Yes
IL-155	F	339	283.8	Yes
IL-156	F	384	194.0	No
IL-157	F	367	4.1	No
IL-158	F	329	65.3	No
IL-159	F	324	370.1	Yes
IL-160	F	318	294.3	Yes
IL-161	F	281	324.2	No
IL-162	F	349	222.6	No
IL-163	F	227	241.4	Yes

Table 5. Summary of tetracycline studies completed during 1995-96.

Amount of Tetracycline in water mg/ml	Group ID	Number of Rats	Mortality
0	T-2	10	50%
0	T-4	10	80%
0	T-6	12	33%
5[1]	T-1	10	90%
20	T-3	10	90%
750[2]	T-5	10	60%

[1] Three-day exposure to tetracycline in water.
[2] Single oral gavage.

Table 6. Results of laboratory tests on Norway rats fed 0.005% warfarin diet as control, and diet treated with tetracycline and metronidazole (Borchert 1997). The three groups had three replications of eight rats each.

Treatment Type and Replication Number	Average Bait Consumption (g)	Average Warfarin Consumed (mg/kg)	Average Days Alive	Percent Mortality
Warfarin (1)	84.4 ± 22.2	14.9 ± 5.25	7.1 ± 3.8	88.9
Warfarin (2)	77.9 ± 21.9	14.7 ± 4.7	9.8 ± 5.3	66.7
Warfarin (3)	80.1 ± 25.3	14.5 ± 4.3	10.2 ± 4.9	66.7
Tetracycline (1)	85.4 ± 25.1	21.7 ± 4.47	6.4 ± 1.5	100.0
Tetracycline (2)	87.2 ± 31.0	15.9 ± 6.5	8.0 ± 3.6	88.9
Tetracycline (3)	75.6 ± 17.1	14.9 ± 6.8	8.1 ± 3.6	88.9
Metronidazole (1)	91.6 ± 28.8	15.6 ± 3.7	7.3 ± 3.7	88.9
Metronidazole (2)	71.6 ± 19.8	17.4 ± 5.0	8.4 ± 3.3	88.9
Metronidazole (3)	80.7 ± 15.7	14.3 ± 4.5	6.4 ± 1.2	100.0

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CONTROL OF RATS RESISTANT TO SECOND-GENERATION ANTICOAGULANT RODENTICIDES

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ABSTRACT: Second-generation anticoagulant rodenticides were introduced to control Norway rats that had become resistant to first-generation compounds. Unfortunately, some rats have become resistant to these as well. The lack of alternative rodenticides with the same attributes of ease of use and relative safety is potentially a serious problem should resistance become so widespread that anticoagulants are no longer effective. However, the second-generation anticoagulants difenacoum and bromadiolone can still be effective provided most rats in a population possess only a low degree of resistance to them. Measures that maximize the uptake of bait, such as using the most palatable formulation, baiting burrows and saturation baiting have to be implemented. The low levels of resistance discovered so far mean that the most potent anticoagulants, such as brodifacoum and flocoumafen, should also control most populations if baits containing either of them are properly applied. These two rodenticides are restricted to indoor use in the United Kingdom and are thus not available to control those rats living outdoors that are highly resistant to all other anticoagulants. Those rats can, however, be controlled with either zinc phosphide or calciferol, preferably after prebaiting. Strategies to manage resistance in the long-term should be implemented before high-degree resistance spreads. One potential tactic is to stop using anticoagulants altogether and allow deleterious pleiotropic effects to reduce the prevalence of resistance in a population. Any attempts to manager resistance are only relevant if the intention is to retain anticoagulant rodenticides, with their undoubted advantages, as the main method of controlling rodent pests.

KEY WORDS: anticoagulants, brodifacoum, bromadiolone, commensal rodents, control, difenacoum, flocoumafen, Norway rats, rats, *Rattus norvegicus*, resistance, rodenticides, UK

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INTRODUCTION

Soon after the introduction in the United Kingdom (UK) in 1975 of difenacoum, the first of the so-called second-generation anticoagulant rodenticides introduced to overcome warfarin resistance (Hadler and Buckle 1992), reports were received from the county of Hampshire in central southern England that it was failing to control some Norway rat (*Rattus norvegicus*) populations (Redfern and Gill 1978). However, these difenacoum-resistant rats still appeared to be relatively susceptible to difenacoum (resistance factor ≈ 4), and therefore resistance was not thought to be a serious practical problem (Greaves and Cullen-Ayres 1988). It was suggested that behavioral or ecological factors were operating in this particular area that tended to reduce the uptake of rodenticide bait and allowed these "slightly" resistant animals to survive. Support for this idea came in later studies (Quy, Shepherd and Inglis 1992; Quy et al. 1992) in which the relatively greater abundance of alternative food, particularly stored cereal, in the Hampshire area was a relevant factor. Indeed, Quy, Shepherd and Inglis (1992) suggested that earlier reports (Greaves, Shepherd and Quy 1982) that resistance to two other second-generation compounds, brodifacoum and bromadiolone, was a main cause of treatment failure in the Hampshire area, were premature. It might have been that rats survived treatments largely because they ate little or no bait, as demonstrated in later trials in the same area (Cowan et al. 1995). Furthermore, because resistant rats from Hampshire required more vitamin K than susceptibles (Greaves and Cullen-Ayres 1988), resistant individuals had a selective disadvantage. Withdrawal of anticoagulants should result in resistant rats being replaced, in due course, with susceptible ones, as reported in earlier studies on warfarin resistance (Partridge 1979). This could only occur, of course, if susceptible alleles were present in the existing population or in nearby reservoir populations.

Norway rats that are resistant to second-generation anticoagulants have also been reported in other European countries. A survey in 1992 reported difenacoum and bromadiolone resistance in Denmark, France and Germany with an additional report of bromadiolone resistance in Holland (Myllymaki 1995). At the time of the survey, no European country, other than the UK, had reported resistance to brodifacoum or to two other relatively new second-generation anticoagulants, flocoumafen or difethialone (the latter not registered for use in the UK). However, the author of the report doubts that the full extent of anticoagulant resistance across Europe was discovered, due to the limited facilities available in most countries. In Germany, the area infested by resistant rats appeared limited to about 8,000 sq. km in the northwest of the country with, apparently, anticoagulant susceptible rats elsewhere (Pelz, Hanisch and Lauenstein 1995). The authors suggested that continued use of difenacoum and bromadiolone in the resistance area might lead to further selection of genes that conferred resistance to the most potent compounds. Consequently, it was suggested that the resistant rats should be controlled using the most potent anticoagulants, brodifacoum, flocoumafen or difethialone.

In this paper, the practical aspects of dealing with widespread resistance to second-generation anticoagulants will be considered, including measures to counter the problem in the short- and long-term, although at present long-term solutions are mostly speculative, because no one has attempted to implement a rodenticide resistance management strategy.

DEGREES OF RESISTANCE TO SECOND-GENERATION ANTICOAGULANTS

The development of blood clotting response (BCR) tests for detecting resistance to second-generation coagulants (Gill et al. 1993, 1994) has enabled relatively quick determination of resistance as well as sequential testing of individual rats to identify how many different anticoagulants they are resistant to. Buckle, Prescott and Ward (1994) argued that because BCR tests are sensitive enough to detect small shifts in susceptibility, they do not necessarily predict a practical control problem. They provide, however, the technology not only to distinguish susceptible rats from resistant ones, but also to differentiate between low- and high-degrees of resistance. They have now become part of the resistance detection methodology in many European countries (e.g., Pelz, Hanisch and Lauenstein 1995). The distinction between low- and high-degree resistance is not clear cut. Cowan et al. (1995) divided rats into groups on the basis of their response to difenacoum in BCR tests. Rats with log10 PCA (percentage clotting activity) <1 were susceptible, 1-1.5 had low-degree resistance, and >1.5 had high-degree resistance. Animals in the latter group would probably survive feeding on field strength baits for several days. With those definitions, the Hampshire rat populations in 1989 to 1992 contained, overall, 51% of animals resistant to difenacoum (log10 PCA >1), but only 22% with high-degree resistance (log10 PCA >1.5). The mean difenacoum PCA for 253 rats was 23.15 ± 1.53. There were insufficient animals tested to estimate the prevalence and degree of bromadiolone resistance among those populations, but from a sample of 19 rats, the mean corrected PCA was 38.1 (log10 1.58) $\pm$ 5.92. The prevalence of warfarin resistance was 84%.

In contrast, most rats in a population discovered in Berkshire, UK (Quy et al. 1995) were highly resistant to both difenacoum (mean PCA 67.5 ± 4.3) and bromadiolone (mean corrected PCA 107.9 ± 5.5). Although some rats died on a 5- or 6-day no-choice feeding test using 0.005% (w/w) bromadiolone, no rat was classified as susceptible on any BCR test. From a total of 50 rats given a bromadiolone BCR test over a two-year period, only one was classified as having a low degree of resistance; of 60 rats given a difenacoum BCR test over the same period, two were found with low-degree resistance. It was assumed that all rats were warfarin-resistant.

In the UK up to 1995, populations containing rats with some degree of resistance to difenacoum have been found in central southern England and also the southeast and east Midlands; bromadiolone-resistant rats have been found in the central area of England between the south coast and the Humber estuary (MacNicoll et al. 1996). The authors also reported low-degree resistance (determined by a feeding test) to brodifacoum in rats from four farms in central southern England and a degree of resistance to flocoumafen (by BCR test) in rats from one farm. All the rats were tested after reports were received of control problems on farms, so it is unclear whether these were isolated incidents or that they reflected the widespread nature of anticoagulant resistance in the UK. Since 1995, rat populations have been sampled in new areas without prior knowledge of control problems. Of the 22 populations tested, 75% contained individuals resistant to warfarin, 30% resistant to bromadiolone, and 5% resistant to difenacoum. The wide distribution of populations containing resistant rats effectively rules out any kind of containment operation, such as the one instigated in the 1960s in an attempt (which failed) to eliminate warfarin-resistant rats from an area along the Anglo-Welsh border (Drummond 1966).

IDENTIFYING RESISTANCE AS A CAUSE OF CONTROL FAILURE

The use of chemical markers to measure how much bait individual rats consume in the field, together with BCR tests to determine their resistance status, has enabled detailed analysis of the reasons for poor control to be carried out (Quy et al. 1992; Cowan et al. 1995; Quy et al. 1995). It is now possible to establish the primary cause of each treatment failure. Such techniques are not immediately available to the occupier or pest control operator who has to control an infestation, and they would probably be seen as prohibitively expensive and a cause of further delay in eradicating a problem. In those situations, the only observations of treatment progress will be bait take and the number of dead rats found. Essentially, two problems are encountered whenever the treatment appears to be failing—either little or no bait is eaten, or bait is eaten but no dead rats are found. A poor uptake of bait does not immediately signal resistance, but it may be important if low-degree resistance is present and the small amount eaten would otherwise kill fully susceptible rats (Quy et al. 1996). In contrast to first-generation anticoagulants, the increased potency of second-generation compounds has meant that as rats may acquire a lethal dose after one feeding, a continuous supply of bait may not be necessary provided the rats are not resistant, a concept know as "pulsed baiting" (Dubock 1984). The practical consequence is that bait points need not be checked as frequently to maintain efficacy, resulting in lower costs to the operator. Nevertheless, where rats are resistant and the most palatable formulation is being used, yet bait take is insufficient to kill, then failure to control could be due to the combined effects of poor bait take and resistance. If pulsed baiting is being used, increasing the amount of bait to maintain a surplus may give better results.

Where bait is readily consumed and there are adequate numbers of bait points but no signs that rat activity is decreasing, then resistance must be considered. The warning dyes added to commercial rodenticide formulations that color droppings are useful indicators that rats are eating the bait. Bait eaten continuously from particular points for longer than seven days should arouse suspicion, whereas bait points reactivated after the same time interval suggest probable reinvasion (Quy et al. 1994). It follows that bait points should be inspected two to three times a week and records kept to avoid drawing the wrong conclusions. In many cases, dead rats are found and, if a sufficient number are killed to reduce the infestation to below nuisance levels, the reason why some individuals have survived is likely to be seen as immaterial.

Prior knowledge that the area contains warfarin-resistant rats is important when second-generation anticoagulants appear to be failing. It appears that a prerequisite for the selection of resistance against the more potent anticoagulants is the presence of warfarin-resistant animals, which probably form a large proportion of the population. Greaves, Shepherd and Gill (1982) recorded a prevalence of 85% warfarin resistance in the first field investigation of difenacoum resistance in 1979-80. Samples of rats in which all members survived a warfarin feeding test were found in the USA in 1971 (Jackson and Kaukeinen 1972), but the resistant populations were successfully controlled with zinc phosphide, as second-generation anticoagulants were not then available. Pelz, Hanisch and Lauenstein (1995) reported a prevalence of 95.7% warfarin resistance on two farms where bromadiolone and difenacoum resistance was also present.

MANAGEMENT OF LOW-DEGREE RESISTANCE

The lack of alternative rodenticides with the same attributes of practicability and relative safety as anticoagulants means that, contrary to what one might normally recommend for resistance management, anticoagulants may still be the active ingredients of choice provided the degree of resistance is low. The option to use a non-anticoagulant, if one is available, is still there and it has the advantage in that it would kill both resistant and susceptible rats. Rather than withdraw all anticoagulants, in some areas of the UK bromadiolone-resistant rats can be controlled with difenacoum (MacNicoll et al. 1996). If rats also become resistant to that, then brodifacoum or flocoumafen are, subject to restrictions, available. Only a small number of populations have been identified that are bromadiolone-resistant but difenacoum-susceptible. Although bromadiolone baits appeared to be more successful than difenacoum baits against resistant rats in Hampshire (Greaves, Shepherd and Quy 1982), the difference between the resistance factors towards the two compounds (approximately two and four, respectively) was thought to be of no practical consequence (Cowan et al. 1995). A contributory factor to the apparently greater success of bromadiolone baits might have been that baits containing bromadiolone tend to be more palatable than those containing difenacoum (Quy et al. 1996). Thus, rats with a low-degree of resistance might have accumulated a lethal does more quickly during the bromadiolone trials than during the difenacoum trials. The aim in treating a population with low-degree resistance would be to maximize bait take by, for example, placing baits in burrow entrances rather than containers—this technique appears to be beneficial on sites with alternative food sources (Quy et al. 1996). Unfortunately, this option is not available if circumstances demand the use of tamper-resistant bait stations. Moreover, a bait base acceptable to the target population should be used. The advantage of using potent compounds in less acceptable formulations, such as wax blocks (Buckle 1994), to reduce non-target risks, would be compromised. When three different loose-grain baits, all containing bromadiolone, were tested against warfarin-susceptible rats and rats with a low-degree of resistance to difenacoum and bromadiolone, the least palatable formulation was relatively unsuccessful at controlling the resistant populations, although it did eliminate the susceptible ones (CSL, unpubl.). The availability of rodenticide concentrates would allow local mixing of baits that maximize palatability and consumption. Another detrimental aspect of controlling rats with a low degree of resistance is a return to surplus baiting, where previously minimal quantities of bait were sufficient. Pulsed baiting (Dubock 1984) relies on the high potency of anticoagulants such as brodifacoum and flocoumafen to produce the same degree of control with less bait and less labor input. The benefits in terms of non-target risks are that there is a reduced amount of bait available at any one time during a treatment. In taking steps to maximize bait take to overcome low-degree resistance, it must be recognized that risks to wildlife are likely to increase.

Some rat populations in the Hampshire resistance area contained individuals that had ingested doses of difenacoum or bromadiolone in excess of 100 mg/kg body weight and survived (Cowan et al. 1995) and might, therefore, have been considered to be highly resistant. Although these animals represented less than 1% of the survivors examined, the implication is that populations containing predominately low-degree resistant animals, may, nevertheless, contain a few highly resistant individuals. This reinforces the need to carry out a thorough treatment and kill all rats. However, eliminating the last few survivors of a treatment could be disproportionately costly and, on a busy farm, small numbers of animals would probably be overlooked. Further applications of these rodenticides against highly resistant survivors and their descendants may eventually produce a population that is completely refractory to treatment. The fact that, to date, there have been no reports of serious control failures, unequivocally due to resistance, from the Hampshire area suggests either that the selection pressure has not been sufficient, or that highly resistant populations exist there, which are small and not particularly troublesome, or are being controlled by illegitimate means. When populations do become troublesome and seem to be uncontrollable because of high-degree resistance, the additional cost of alleviating the problem may be substantial. It now appears that a high-degree of resistance can be sustained within some populations (Quy et al. 1995).

MANAGEMENT OF HIGH-DEGREE RESISTANCE

The success of anticoagulants, particularly second-generation compounds, no doubt hastened the end of some potentially useful non-anticoagulant toxicants. It seems unlikely that more potent anticoagulants can be produced to overcome the new forms of resistance that are now appearing (Hadler and Buckle 1992). While it appears that the most potent anticoagulants are still effective, for all practical purposes, against all rat populations, both brodifacoum and flocoumafen are registered for indoor use only and for use by professional pest controllers only. They are currently not available to control infestations of rats resistant to difenacoum or bromadiolone, except in those situations where indoor application of these rodenticides can control a population of rats that may live mostly outdoors. Stopping the use of anticoagulants would, in theory, reverse the selection pressure in favor of susceptible rats. It might take some time for this to happen, particularly if any deleterious effect did not prevent individuals from breeding. In one example (Quy et al. 1995), the descendants of survivors of a population with a high-degree of resistance to bromadiolone and difenacoum were tested after 17 months with apparently no intervening exposure to anticoagulants. The degree of resistance had reduced, but was still too high to be confident of any success with difenacoum or bromadiolone. It was likely that neighboring rat populations, as potential sources of immigrants, were also highly resistant to anticoagulant rodenticides, raising the prospect that the occupier of the site may be unable to achieve any satisfactory control for the foreseeable future with those rodenticides. A further problem, foreseen by Greaves (1994), is where a beneficial pleiotropic effect of the resistance gene occurs which is maintained without artificial selection. If that occurred, resistance would be difficult to eliminate. The longer that resistant populations are allowed to persist, the more likely it is that mechanisms will evolve that dilute the pleiotropic costs of resistance (Cowan et al. 1995).

Faced with a population of rats that could not be controlled with second-generation anticoagulants for reasons of resistance or legal restraints, Quy et al. (1995) used calciferol, even though previous use of this rodenticide had failed to alleviate the problem. The only other option was zinc phosphide, which had also been tried without success. Previous experience with both compounds suggested that, to avoid inducing bait aversions, a period of prebaiting would be needed to maximize the effectiveness of the treatment, given the possibility that a population of highly resistant rats, made bait-shy by sublethal poisoning, could produce an "unpoisonable" infestation.

The likelihood of persuading the majority of rats to eat the prebait, wholly and continuously, hence improving the chance of success with a relatively fast-acting poison, may depend on the type of farm. The continual disturbance that takes place in some farm habitats, particularly those rearing livestock, appears to reduce neophobic responses to bait and bait containers (Quy et al. 1994). In these situations, the prospects for substantial reductions in rat numbers should be good, provided an appropriate toxicant is available. The disadvantage, however, is that when anticoagulants are used on livestock farms, susceptible and partially resistant rats would be quickly eliminated and a highly resistant population selected, as Quy et al. (1995) observed on a pig farm. In place of an unpoisoned prebait, a treatment could start with an anticoagulant bait, which would kill any susceptibles and could also become a prebait for an acute poison such as zinc phosphide. It would be advisable to ensure that the bait base of the anticoagulant formulation was available to mix with the acute poison, as local pesticide regulations might not allow two poisons to be added together. As with any treatment with a fast-acting toxicant, errors in bait placement could undermine effectiveness and complete eradication would be unlikely. The advantage of this approach for the occupier is that, depending on the proportion of susceptible rats in the population, the death of some rats might provide some respite. The disadvantage is that, where there are very few susceptible rats, anticoagulant formulations make very costly prebaits.

Using a non-anticoagulant with prebaiting would probably not require much more labor input than a surplus-baiting anticoagulant treatment. However, such treatments rarely kill all the rats, and a high percentage reduction of a large population may still leave an unacceptable number of survivors. This occurred following the calciferol treatment reported by Quy et al. (1995), and it required extensive trapping to remove the residual infestation. It is noteworthy that the calciferol formulation used in that trial, which was different to the formulation first used on the farm, is not generally available in the UK and is expensive. A relatively new, non-anticoagulant rodenticide in the market place is bromethalin, which is not registered for use in the UK. Bromethalin requires no prebaiting as it does not apparently cause bait-shyness (Jackson et al. 1982). The development of alternative rodenticides is essential to help slow down, at least, the evolution of widespread resistant rat populations.

The use of non-anticoagulant rodenticides in "fire-brigade" actions must be seen as a short-term measure, alleviating urgent control problems. If there is a will to retain anticoagulants for future use in rodent population management, then strategies to control resistant rats in the long-term must be put into practice. So far, this has not occurred. Smith and Greaves (1987) considered resistance management strategies and discussed the theoretical and practical problems with their implementation. One suggestion was the use of a sterilizing agent to treat survivors of an anticoagulant treatment, although a suitable chemical or immunocontraceptive is currently not available. Earlier, Lazarus and Rowe (1982) suggested incorporating a similar agent into the prebait prior to an acute poison treatment, after they had prevented an island rat population from breeding for 10 months by using a synthetic oestrogen. Methods that reduce rat populations gradually over many months are not likely to be well received by occupiers, but small numbers of animals might be tolerated on farms, although probably not in urban or industrial premises. Smith and Greaves (1987) saw a potential advantage in allowing a small population to remain, even if all members were resistant, because it might repel immigrants for a time, thereby slowing down reinfestation.

Should brodifacoum and other highly potent anticoagulants be part of a long-term strategy to control rats resistant to all other anticoagulants? For that to happen, restrictions, where they apply, would have to be relaxed and the potential consequences of non-target hazards considered. Wider availability may result in the evolution of populations of rats also resistant, for all practical purposes, to those compounds. Rats with a low degree of resistance to brodifacoum have already been discovered (Gill and MacNicoll 1991). However, the use of brodifacoum against rats resistant to warfarin, but not to any other second-generation compound, might prevent resistance to difenacoum or bromadiolone evolving almost indefinitely. Thus, in these circumstances, the advantages of pulsed-baiting with brodifacoum, particularly the reduced non-target risk, would remain.

In contrast to pesticide-dominated strategies to control resistant rats, more environmentally-friendly methods may become prominent if chemical control fails. Whatever the resistance status of populations, techniques that reduce the carrying capacity of a habitat, such as a farm, can potentially reduce the scale of a control problem. Around farm buildings and particularly in urban areas, reducing harborage and denying access to food sources should be possible without affecting populations of other animals. Among field margins this is more problematic, and it has been argued that selective destruction of a pest with a pesticide is preferable (Howard 1967). Unfortunately, this depends on a suitable pesticide being available. Control without the use of anticoagulants would, of course, remove the selection pressure towards increased anticoagulant resistance.

CONCLUSIONS—IS RESISTANCE A PROBLEM?

The unusually large rat population reported by Quy et al. (1995) was a consequence of a favorable habitat combined with a failure to control with anticoagulant rodenticides. The number of rats present reflected the carrying capacity of a typical livestock farm in central, southern England. Populations rarely increase to the limits of the habitat, because control measures are usually instigated long before such a limit is reached. With the controversy surrounding the significance of resistance to second-generation anticoagulants, it is difficult to present any view that is not seen as biased by one party or another. Manufacturers of rodenticides clearly do not like their products to be criticized. Professional pest controllers do not like to be accused of failing to provide a satisfactory service. Legislators feel bound to respond to public concerns about environmental safety and humaneness. The public, presumably, still wants rats to be controlled. Given the high costs of developing and marketing a new rodenticide, it could be argued that industry will take action when it is seen to be profitable. By that time, the highly resistant populations, currently limited to a small area in central, southern England, may be distributed across the country. Smith and Greaves (1987) emphasized the importance of resistance monitoring and early action to eradicate resistant rats. They also stressed the need to stop using anticoagulants when resistance is detected. Although there is no routine monitoring program in the UK, the development of laboratory-based tests and extensive testing of rats from field populations over the last 20 years has been an invaluable and unique tool in understanding the nature of rodent control problems.

The lack of alternative rodenticides is potentially serious; a catalog for a well-known supplier of pest control products in the UK lists 41 rodenticide formulations for the control of rats, of which only two are non-anticoagulants (both zinc phosphide). The danger would be that, faced with an urgent need to control an infestation, occupiers or their agents might resort to unsafe or illegal methods to eradicate the rats if all legitimate means failed. Jackson and Kaukeinen (1972) reported that the farmers and pest control operators depended on the use of anticoagulants to save tidying up the farms to make them less attractive to rats. That view appears to still be widely held. The effect of resistance is probably insidious, only coming to people's attention when other factors unrelated to resistance allow rat population density to increase above what is regarded as normal. Unfortunately, preventive action is hard to justify to those who may be inconvenienced or put to extra expense, when there is uncertainty about when or if future control problems will arise.

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THE EFFICACY OF GLUE TRAPS AGAINST WILD POPULATIONS OF HOUSE MICE, *MUS DOMESTICUS*, RUTTY

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ABSTRACT: Field research was conducted from Purdue University during 1991 to 1993 to examine some aspects of the efficaciousness of the various types of glue traps against wild populations of house mice. The research was conducted in agricultural and livestock buildings containing various infestation levels of mice. Tests compared the capture and escape rates of glue boards vs. trays, covered vs. uncovered glue traps, and glue traps vs. snap traps, and multiple catch curiosity traps. Observational work, via night vigils, was also conducted to note the behavioral response of mice to glue surfaces, including the behavioral aspects of mice neutralizing glue surfaces in well-used runways. These field tests indicate many mice, upon initial interactions with glue traps and surfaces, are repelled by them and either learn to avoid them or neutralized them in some manner. Results of comparison trials between glue traps and non-glue mouse traps also indicate strong differences in interaction and capture rates favoring non-glue traps. It is hypothesized that when glue traps are successful, it is likely due to mice traveling kinesthetically along frequently used runways in which traps are placed, or to factors associated with age class of mice. These studies have strong implications for rodent pest management programs in facilities which are restricted to non-chemical approaches (e.g., food handling establishments and sensitive accounts).

KEY WORDS: house mouse, *Mus domesticus*, glue traps, snap traps, multiple catch traps, investigative behavior, kinesthetics

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INTRODUCTION

Glue traps are widely used by homeowners, food processors, and pest management professionals in attempts to control rodents; particularly mice. The impetus for this field study resulted from repeated calls for assistance from warehouses and food processing plants which had been relying on glue traps as their primary indoor mouse control tool, but yet mice were persisting. Visits to these sites confirmed that although some mice were being captured on the glue traps, other mice remained uncaptured and active for prolonged periods in areas where fresh traps were abundant and present in mouse runways and high mouse activity areas. Some mice, it seemed, were ignoring, avoiding, or repelled by the glue traps in their territories.

This led to a literature search in efforts to locate a study which addresses the efficacy of glue traps when used against wild populations of mice within structures. Not only is such data and discussion lacking, but efficacy testing procedure and standards for glue traps have never been developed by the pest control industry, nor does the EPA require the registration of glue trap products. Frantz and Padula (1983) also noted this during their review of glue traps.

Several publications address glue traps on an informal basis, (e.g., Anon. 1981; Fitzwater 1982; Marsh 1982; Frishman 1992) and on a more formal level, Frantz and Padula (1983) provide an laboratory study addressing the mode of action of glue entrapment on lab mice, and the behavior of confined lab mice around glue traps. Their results are important in that they provide insight into the interaction between mice and glue traps. Still, these researchers note the importance of the difference between a lab environment and a natural environment and stressed the need for testing glue traps in the field.

This paper reports the results of several different field tests which were conducted over a period of three years that measure the efficacy of glue *board* traps and glue *tray* traps used in various combinations and in comparative tests against various types of non-glue traps against naturally occurring, structural infestations of free-ranging wild populations of the house mouse, *Mus domesticus*.

MATERIALS AND METHODS

The field tests for this study were carried out during 1991 to 1993 in various livestock, agricultural, and warehouse buildings in central Indiana infested with populations of wild house mice, varying in population size. All buildings were relatively new ($\leq$10 yr.), heated and insulated. Some sites contained livestock in pens or cages. Food (livestock feed) was readily available to the mouse populations at all sites. Thus, the sites resembled other commercial urban buildings in which mice become pests due to the availability of food, shelter, and warmth.

All buildings were screened prior to testing to ensure building or climatic factors would not negatively affect the glue traps or non-glue traps used in the study. Thus, only buildings, or those portions of building, where floor areas were not dusty, dirty, or wet prior to, or during, the test periods were used for tests. Additionally, all test areas remained at temperatures ranging between 18 to 30°C at night depending on the specific climatic conditions and building for each test.

For those tests where traps were in position for more than one night, the adhesiveness of each trap was checked daily using a clean metal spatula blade to ensure the trap was not affected by any dust or dirt. Glue traps containing any captures, or traps containing fur residues from previous mice where replaced with new traps. Successful metal repeating mouse traps were replaced with clean (hot water and ammoniated detergent/rinse) traps to avoid biasing traps due to pheromonal cueing.

All glue traps used in this study were, and are, available from popular manufacturers and supply distributors, and the basic make up of the traps in design and glue compositions remain, for the most part, the same today, although relatively minor changes have been made among some brands and models since these tests were conducted.

Glue *board* traps are constructed with thin levels of glue varying from 1 to 2 mm in thickness mechanically applied at the factory to thin cardboard platform. The platform can be placed out unfolded or folded to form a tent-like appearance. Glue *tray* traps are filled with glue to a thickness varying from 4 to 6 mm. Various types of plastic or cardboard covers are available for the glue tray traps. Both styles of traps are available in mouse-size traps and rat-size traps. The dimensions of the traps are listed with the specific test below. The variances in the composition and mixtures of the glue ingredients among models and brands were not considered. A discussion of the materials used as sticky adhesives for rodent and bird glue traps and repellents is provided by Fitzwater (1983).

All glue and non-glue traps used in this study were obtained either by purchasing the traps from pest control supply houses, or via the manufacturers directly.

Additional methods (specific trap dimensions, number of traps, trap spacing, etc.), are discussed with the specific test.

Test I. Glue Traps vs. Non-Glue Traps

Test IA—Cardboard glue traps vs. double sets of professional model mouse snap trap. Based on preliminary observations of glue traps failing to control mice in two large food manufacturing plants, this test was initiated to gather a cursory evaluation as to how the inexpensive cardboard glue board traps would perform against standard mouse snap traps on capture performance only.

Within three rooms, 12 Victor cardboard mouse size M320 glue traps folded into a "teepee" configuration, and 24 Victor M133 professional model (i.e., expanded trigger) mouse traps were installed along wall areas and various shelving areas exhibiting mouse activity (e.g., droppings, urine pillars). Because each glue trap is capable of capturing more than one mouse per trap setting, two snap traps per placement were made for every one glue trap. In this way, approximately the same amount of space occupied the mouse's runway, by the new objects, and the opportunity to capture more than one mouse was available at each trap station. The snap traps were placed with approximately 2.5 cm separating the traps.

The traps were installed in an alternating treatment pattern at about 1.5 to 2.0 m intervals, but various closets and shelving areas were also utilized according to mouse activity and space allowing for trap placements. All traps were installed in "runway" areas (corner placements were avoided). Because the glue traps available for this test contained a "peanut oil" attractant, applied by the trap manufacturer, the snap traps were baited with a tiny smudge of peanut butter on each of the trap triggers. All traps were installed between 1500 to 1700 hr. and checked the following morning between 0700 to 0900 hr. This test was run for one night only, and was conducted during the spring of 1991.

Results. The snap traps captured a total of 54 mice per 96 traps for a total capture rate of 56.2%. The glue traps captured a total of only four mice (8.3%) (Table 1). Escapes and non-committal interactions between the trap treatments were not measured in this test.

Test IB—Mechanical repeating multiple catch traps vs. glue traps. As a follow up to Test IA, it was desirable to evaluate the difference between commonly used mechanical multiple catch traps ("curiosity traps") and glue traps, as both types of traps are widely used in the food industry. The tests were run in various combinations and designs as described below.

Table 1. A comparison of the total mouse captures by professional model mouse snap traps and folded cardboard glue traps.

Building	Snap Trap (n=24)	Folded Cardboard Glue Trap (n=12)
GF 1	16	2
GF 2	13	1
Vestibule areas	9	0
GF 3	16	1
Totals	54	4

Test IB(1)—Comparison of a wind-up curiosity trap and folded cardboard glue trap. The objective of this test was to measure the difference between interaction rates and capture rates between a widely used multiple-catch mouse trap (The Ketch All®; Kness Manufacturing), and a folded cardboard "elongated" mouse glue trap (The Trapper® Bell Laboratories).

This test was conducted four to five weeks following the snap trap tests utilizing the same buildings, and in a similar fashion, although the Ketch All® trap replaced snap traps. The Trapper® Mouse Pro (Bell Laboratories) cardboard mouse trap forms a four-sided tunnel measuring 18 x 5.5 x 3.5 x 6.0 cm with a glue covering measuring 9 x 14 cm. The adhesive surface begins one centimeter from each end of the trap. Conceivably, the glue trap contains enough space to capture up to three mice. The Ketch All® trap, if wound completely could capture up to 15 mice. For this test, however, each trap was wound enough to allow for only three good revolutions of the trigger paddle. If any more than three mice were found within either trap, they were ignored. Twelve (12) traps of each treatment were installed into each room. For the purposes of this paper, only a summary of overall performance between trap treatments is presented. This test was run for one night only.

Results. The results of Test IB(1) are presented in Table 2. Similar to the results seen in the snap trap comparison tests, the glue traps captured only seven mice among 48 traps for a total of 13.0% of the total mice taken from all four areas. The Ketch All® trap captured a total of 47 mice among 48 traps (87% of all mice captured).

Test IB(2)—Comparison of a non wind-up multiple catch traps to covered and uncovered glue tray traps. This field evaluation compared the Tin Cat® (Woodstream Corporation) repeating mouse trap with uncovered J. T. Eaton's rat-sized glue tray traps and the same tray trap installed within an Eaton's glue trap cover. The Tin Cat® is a non-windup teeter totter ramp style repeating mouse trap measuring 16.5 x 27 x 6.5 cm. The entry openings to the trap measure 2.5 x 3.5 cm and are 0.7 cm off the floor. The glue tray trap measured approximately 12 x 28 cm and is filled with approximately 4 to 6 mm of glue. With the cover on the glue trap, a tunnel opening of 5.0 to 7.5 cm tall and 12.5 cm wide is created.

Tests were conducted in an poultry layer research facility containing 14 rooms and long hallways. The various hallways and storage areas throughout the building contained significant levels of mice. A total of 19 traps of each treatment were installed until the floor space was completely occupied throughout the facility. The traps were run for a period of six days, at which time various cleaning and operational activities of the facility caused the termination of the trapping program. Thus, a total of 114 trap nights per trap treatment were run. All traps were run each morning, and all captured mice were removed from the premises and euthanized. Any trap of any of the three treatments that had a successful capture or showed signs of mouse interaction (e.g., droppings or hair on a trap) was replaced with a new glue trap or a clean (i.e., thoroughly washed) Tin Cat®. Traps were installed in randomized fashion throughout the complex with approximately 2.5 m spacing between all traps.

Results. The results of Test IB(2) are shown in Table 3. The repeating Tin Cat® captured a total of 96 mice or 67.6% of all mice captured over the six nights of trappings. The uncovered glue tray traps captured a total of 30 mice (21.0%), while the fewest mice were captured on the covered glue traps with a total of only 16 mice (11.2%).

Table 2. A comparison of total mouse captures for the Ketch All®® repeating mouse traps and folded cardboard glue traps.

Room	Ketch All® Trap (n=12)	Folded Cardboard Glue Trap (n=12)
GF 1	11	1
GF 2	9	4
Vestibule areas	6	0
GF 3	21	2
Totals	47	7

Table 3. A comparison of total mice captured per day for the Tin Cat® repeating curiosity trap, a covered glue tray trap, and an uncovered glue tray trap.

Day	Tin Cat® Trap (n=19)	Uncovered Glue Tray (n=19)	Covered Glue Tray (n=19)
1	27	13	5
2	18	6	3
3	18	7	3
4	16	2	1
5	10	1	4
6	7	1	0
Total	96	30	16
Percent of Total Mice Captured	67.6	21.0	11.2

Test II. Glue Trap Model Comparisons

The objective of this field test was to measure any interaction and efficacy difference between the various types of glue traps. Open vs. folded boards were compared, as well as glue tray traps vs. glue boards. It was of interest to note the effects of a glue trap lying flat on a surface as compared to a folded trap which creates a tunnel to which the mouse must enter. Additionally, it was of interest to see whether or not the lip on a glue tray which raises the surface of the trap off the floor by approximately 5 to 7 mm might affect the interaction of exploring or running mice as compared to the surface of a cardboard trap lying relatively flat along the surface.

These tests were carried out in moderately to severely infested rooms among three grower-finisher confined hog buildings, as well as within the poultry research complex mentioned above. For test IIA, 21 traps of the Victor M 183 were alternated in placement, with spacing of approximately 2 to 3 m. The test was run for one night only.

For Test IIB, a total of 128 traps of each treatment was installed into the buildings. The Bells' mouse size (12.2 x 8.3 x 1.0 cm) Trapper® glue tray traps filled with approximately 4 to 6 mm of glue were used in this study. The glue board traps were the Victor M 183 mouse traps as described above. Trap treatments were alternated in placement, with spacing of approximately 2 to 3 m. The test was run for one night only.

Results. The results of Test IIa are shown in Table 4. Of the total number of 19 mice captured during the night, 14 (73.6 %) of the mice were captured on the open boards, as compared to 5 mice (26.3%) captured among the folded traps. Although, the overall number of mice captured between treatments and among the three rooms was very low, it is not necessarily an indication of a low population of mice, as it might be an aversion of mice to interact with these devices. Moreover, a total of 38 traps received interactions, but non-committal activity, and moved traps represented 30% of the total traps installed.

The results of the comparison for Test IIb are shown in Table 5. In this test, interactions with traps included either captures or indications on any activity on the trap surfaces (e.g., hairs, droppings). The interaction rates of the trays were less than half of the interactions with the boards (23.4% vs. 50.7%). The glue tray traps successfully captured a total of 22 mice that interacted with the tray trap compared to 31 mice captured with the glue boards. This is also reflected in the percentage of escapes or non-committal interactions with those traps receiving interactions. With the trays, escapes were much lower (16.6%) as compared to the open board traps which showed nearly half of all traps (47.6%) allowing escapes or repelling the mice from committing more to the trap surface.

DISCUSSION

Natural Aversions by Mice to Dangerous Surfaces

Many factors are likely to affect the efficacy and repellency of glue traps against rodents within real world biological and non-biological factors (Corrigan 1994). This paper, however, is primarily concerned with the possible biological and behavioral factors since all styles of glue traps were found in many cases to be avoided, and were significantly less effective in capturing mice than non-glue traps.

For many years, professionals and non professionals alike have visually witnessed mice jumping over and running around glue traps. But, aside from a reactive jump over a new object (as they do with other traps as well), it seems some mice are capable of detecting the danger of a sticky surface. In the field it is common to find evidence (droppings and/or hair) of mouse encounters, interactions, and "escapes" on glue traps. Moreover, pest management professionals often encounter tufts of hair on cockroach monitoring traps, as well as pieces and parts of cockroaches which have been consumed off of glue boards by mice. Such field observations combined with the data as shown in these

Table 4. Total number of captures and escapes of mice for folded and unfolded glue board traps.

Building	Open Glue Board (n-21)	Folded Glue Board (n=21)	Boards Moved Out of Runway	Glue Traps Indicating Escapes or Non-committal Activity
BG 1	7	3	2	8
BG 2	3	0	4	7
P1	4	2	7	10
Totals	14	5	13	25

Table 5. Interaction rates, captures, and escapes of mice between open cardboard glue traps and open plastic tray glue traps.

	Glue Trap	Trap Interaction (%)	Captures	Missing Traps	Traps Indicating Escapes or Noncommittal Activity
			n=30		n=30
N=128	Tray	30 (23.4%)	22 (73.3%)	3	5 (16.6%)
			n=65		n=65
N=128	Open board	65 (50.7%)	31 (47.6%)	3	31 (47.6%)

studies clearly indicate that many mice are able to determine and avoid the danger of sticky surfaces.

The repellency of glue traps has been noted occasionally in trade journals and educational leaflets (e.g., Frishman 1992; Marsh 1982; Story 1982). Frantz and Padula (1983) also reported that some laboratory mice shifted their activity away from pathways that contained glue boards.

The biological mechanisms and interactions involved with mouse explorations and behavior relative surface substrates is lacking or scarce. But, significant insight into the possible biological and behavioral mechanisms associated with rodents avoiding dangerous surfaces may be provided by studies and discussion on the vibrissal apparatus of rodents (e.g., Sokolov and Kulikov 1987; Barnett 1975, 1988). These studies and papers discuss the location, function, and use of the various groups of the vibrissae sensory organs on rodents. Sokolov and Kulikov (1987), show that specific groups of vibrissae are used for general orientation to, and detection of, various substrates. By means of the whisker vibrissae, for example, the animal investigates the environment in which it is moving (i.e., detects obstacles and feels unfamiliar objects). Other groups of vibrissae are used to protect the snout from damage, while others help control movement of the rodent in relation to various substrates such as soil, stones, tree branches, etc.

The facial vibrissae of the adult house mouse can reach lengths slightly greater than 2.5 cm. Sokolov and Kulikov (1987) illustrate how rodents project their facial vibrissae out in front of the animal to "feel" and explore the area immediately in front of them. Using their vibrissae for this function, house mice would certainly be equipped to avoid a surface which grabs and holds these sensory tactile organs. Moreover, other vibrissal groups, located on the feet and belly, may also play a role in the avoidance of dangerous surfaces.

Presumably, following a dangerous encounter with a sticky surface and object, mice are capable of remembering the encounter due to both the visual shapes of the object (i.e., the glue trap), as well as the odors that abound off of glue traps from the resins, rubbers, and other chemicals making up the glue. These odors are easily detectable by people. At the level of a mouse's nose to the glue surface, coupled with their excellent olfactory capabilities, odor association with a dangerous event for this rodent is likely to be significant. The role of the adhesive odors and any possible repellency effects, however, are undocumented.

Glues vs. Non-glue Traps

The overwhelming difference in this study between glue and non-glue traps (snap traps and curiosity traps) as seen in Tables 1-4, at first is surprising and somewhat of a mystery. However, part of the solution lies in observing mice during their nightly forays. Mice tend to make many short trips out of their nests for feeding and general exploratory forays. These trips take them back to the same runways and objects several, and sometimes many, times in one evening. This investigative mode or tendency toward "curiosity" in mice is well documented and reviewed in the literature (e.g., Mills 1947; Crowcroft 1966; Meehan 1983).

Mice, upon exploring a new surface or object for the first time, may be forewarned of the glue surfaces either through their vibrissal apparatus, their sense of smell, or both. A brief negative encounter with such a surface or object allows the mice to avoid the glue object, but to continue exploring and eventually encounter a snap trap.

The snap trap itself is also approached slowly and cautiously (to varying degrees). However, no sticky surface "grabs" at the mouses's foot, face, or body. Moreover, the chemical odors associated with the glue traps are lacking with the snap trap. And, if the snap trap is baited with peanut butter, it is actually likely to be an attractive odor to investigating mice. Nevertheless, it is well known that some mice still approach snap traps with the utmost caution and are capable of licking or stealing bait off of mouse traps without setting off the trap. Moreover, it is important to mention that the folded glue trap design, as compared to the openness of the snap traps, may also have had an impact on the results of the snap trap vs. glue board study (see discussion below).

A similar scenario occurs in the tests comparing glue traps with curiosity traps. When encountering a "curiosity" trap, mice, if in an investigative mode, may elicit an opportunistic response to a potential new burrow (Corrigan 1988). It has been visually observed and documented on film in the field by this author that, although mice investigate new "holes" in their environments, the initial stages of the new hole investigation are often slow and cautious, the same as is seen around other new objects such as the snap traps discussed above (unless the mouse is being chased). Thus, unbeknownst to a pest controller finding a dead mouse in a curiosity trap, the mouse may have spent several trial and error approaches and partial entries to a curiosity trap before committing itself and entering. During the partial entries, the metal or plastic surface of the curiosity trap is of no threat (no "grabbing" of the feet or body) to the rodent, nor would present any repellent nature.

Pheromonal cueing, no doubt, plays a significant positive role in interactions following the first capture (Corrigan 1988; Hurst and Berreen 1985), but any cumulative effect of pheromonal cueing at least beyond 24 hours was not a concern in these tests. It is not known whether or not pheromones play a negative (or positive) role in the interactions and repeated captures of mice on glue traps. However, negative impact does not seem as likely, at least with juvenile captures, as when multiple captures occurred, the capture was often entirely made up of juveniles.

When approaching a covered glue trap in a investigative mode (as opposed to running or being chased to it), the mouse elicits the same "cautious" approach to these "holes" in their path as with the curiosity traps. However, a partial "entry" into this new hole results in the facial and feet vibrissal apparatus adhering to the glue—no doubt causing an alarming reaction to the investigating mouse. It is hypothesized that because the uncovered traps do not present the mouse with a visual hole to enter, a greater chance of the mouse encountering the glue surface on the run, since there is no visual tunnel for them to cautiously explore. This, in part, explains why the non-covered and unfolded traps captured nearly twice as many mice as the covered and folded traps (Tables 3 and 4), although the glue traps were still significantly less effective than non-glue traps.

In the tests comparing trays vs. boards, the lip of the tray traps which elevates the trap off the floor by 6 to 8 mm may help to explain why tray traps did not perform as well in these field tests as the flat cardboard traps (Table 5). With a lip to step up onto, this presents a visual and physical obstacle to an approaching mouse, as well as being off of the mouse's familiar runway floor. Both of these increase the chances for a mouse to make a hesitating approach or a reactionary jump to the trap. The concern of this elevated trap entry area is even considered within the design of current glue tray traps by manufacturers (e.g., Bell Laboratories 1998). Throughout this study, it was common to find captured mice within the middle of the glue trays, or held by only their hind quarters with the front half of their bodies hanging off the trap. As was seen during night vigils during this research, many mice attempted a "long jump" to clear the traps. Weak jumpers were captured either entirely or partially on the traps. In several cases, the tails or only the tips of one rear foot became entrapped, and the traps were dragged away.

In addition to the natural aversions some mice exhibit towards sticky surfaces and traps, another disadvantage associated with glue traps is the role of dust, dirt, and moisture in relation to glue trap efficacy. This relationship is twofold: first, dust and dirt particles are typically carried along the floor air currents within commercial buildings. This particulate matter constantly settles and becomes entrapped on glue trap surfaces. Depending on the cleanliness of a particular structural environment, a glue trap might be rendered ineffective, or at least reduced in effectiveness, progressively over the course of a few hours or days (Walter 1990). Second, while traveling along commercial floor areas, mice themselves may accumulate and carry varying levels of dirt, grease, moisture, or dust particles on their feet and bodies.

In both scenarios, even thin layers of any of these films on glue surfaces may give a mouse the slight edge it needs to escape entrapment—especially in those instances when they slowly approach a trap surface during an investigative mode. In his comments regarding glue traps, Meehan (1983) states: "Some (glue traps) are so ineffective as to be useless for practical purposes, and most suffer from the disadvantages that they will not catch rodents with wet or dusty feet."

Glue "Bridges"

It was common in this study to occasionally discover traps with various types of debris covering the glue surface. Pieces of cardboard, paper, Styrofoam wall and pipe insulation, and dirt excavated from beneath the slab, all were used by mice to build "bridges" over the glue surface of the traps. Sometimes, bridges were built within the first night of a mouse's encounter with the trap. The author observed one mouse make about 100 trips back and forth to a particular glue trap carrying pieces of cardboard and dropping the cardboard on the trap until the trap was nearly covered. Thereafter, this and other mice in the area readily traveled across the neutralized trap, presumably due to kinesthetic behavior, and possible pheromonal attachments and guidance. Debris being deposited on glue traps has also been reported by Marsh (1983), Frantz and Padula (1983), and by many PCOs in the field for both rats and mice.

Bridging activity considered together with the behavior of mice feeding on trapped cockroaches on sticky monitors without committing themselves to the monitor's surface, serves to confirm that not only are some mice aware of the dangerous glue surfaces, but they are also adept at learning or knowing how to neutralize them.

Maximizing Capture Success

Despite the fact that many mice do not thoroughly interact with glue traps, and the fact that the glue traps in these tests failed to perform as well as non-glue traps, there are also many testimonial reports of satisfactory results and indications among pest management professionals (Anon. 1981; Walter 1990; Frishman 1992). But the factors and circumstances that impact glue board success have not been measured. Population densities, age classes, resource availability, environmental and substrate variables, and various other non determinable factors (e.g., pheromonal cueing) may all affect efficacy rates from one situation to another (Corrigan 1994).

In nearly all of the tests conducted in this project, the overwhelmingly majority of captured mice were juveniles (unpublished data). This is often also seen by pest management professionals in the field. Juvenile mice may not have developed fully the necessary physical skills for avoiding real world dangers (predatory avoidance maneuvers) or have not had enough experience in learning to avoid dangerous surfaces. Vibrissal apparatus and sensory organ development may also not be complete enough to provide mice with the maximum physiological advantages of their vibrissae (Sokolov and Kulikov 1987). Too, like other mammals, the juveniles of mice are often noted to be involved in chase and play behavior which may result in less "caution" associated with movement activities. Certainly, more research is needed addressing age-class exploratory and associated avoidance behaviors.

Frequently, multiple captures of young mice occurred on the same glue trap. From night vigils and observations by this author, it was common to see mice traveling along major runways in close proximity to one another. In some cases, this may be chaser and chasee, where both rodents are so distracted by the chase they stumble into the trap (Temme 1980).

In other cases, it was typical to discover 3 to 5 juveniles mice entrapped on one trap. This was likely a result of sibling exploratory forays as young mice follow each other, as well as odor trails left by their mother or their litter mates (Rowe and Redfern 1969). These multiple captures of litter mates was also seen with the use of mechanical multiple catch "curiosity traps" (Corrigan 1988).

Fitzwater (1983) commented that among attractive baits for glue traps, the best attractant may, in fact, be another trapped rodent. And Frantz and Padula (1983) found that trapped rodents do not repel other mice from becoming entrapped.

Perhaps the most important factors relating to successful captures of mice on glue traps are good placement of traps onto high activity runways, and the use of traps models which minimize the "hesitation factor" by presenting as few physical and visual obstructions to a rapidly approaching mouse as possible. This, in turn, would maximize the chances of a mouse totally committing its entire body by unavoidingly stumbling or jumping onto the trap while *kinesthetically* traveling along its runways (Corrigan 1997; Fitzwater 1982).

This is important, as in actuality kinesthetics may play the most important role in the successes of a glue trap. In other words, trapped rodents may most likely be a result of kinesthetically driven rodents which have been using well established runways. As summarized by Meehan (1983) regarding kinesthetic movement, "patterns" of movements of rodents become so ingrained that if rats or mice get used to moving around an obstacle which is subsequently removed, they will continue to move in the same way as if the obstacle was still present.

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WARFARIN RESISTANCE REVISITED

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ABSTRACT: Roughly 50 years ago, the Wisconsin Alumni Research Foundation developed warfarin, the first anticoagulant rodenticide. This product was something close to that desired elusive "magic bullet" of pest management. Warfarin effectively killed rats and mice, required multiple feedings, and had a good margin of safety for non-target species. The widespread adoption of anticoagulants somewhat changed the conduct of rodent control with a shift in interventions toward toxicants and away from education and physical measures. The discovery of warfarin resistance in the United States in *Rattus norvegicus* in 1971, and later in *Mus musculus* and *Rattus rattus*, heralded in another shift in rodent pest mitigation. This shift was the development of more toxic anticoagulant products capable of killing with one or a few feedings and with concomitantly greater risks to non-target species. Development of the more toxic products both anticoagulant and non-anticoagulant continues today, although there is an increasing trend favoring comprehensive approaches (i.e., integrated pest management [IPM]) which: emphasize educating clients and reducing causative conditions; diminishing the role of toxicants; and, when necessary, using products of the least practical toxicity. In this paper, the concept of counteracting anticoagulant resistance is blended with the sometimes necessary use of anticoagulant rodenticides as part of IPM. Nationwide data from the former New York State Department of Health Rodent Control Evaluation Laboratory (in cooperation with the Centers for Disease Control's former Urban Rat Control Program) are examined regarding warfarin resistance in *Rattus norvegicus*. In samples from two dozen project cities, population resistance levels ranged from 1.6% to 76.2% using the standard World Health Organization (WHO) testing criteria. However, most survivors (i.e., resistant rats) of the initial test succumbed upon one or more re-exposure(s) to warfarin using the same WHO testing protocol. The results are surprising and have implications on interpreting the phenomenon of anticoagulant rodenticide resistance and on the pragmatic designing of rodent management programs.

KEYWORDS: rodenticides, anticoagulant resistance, warfarin, Norway rat, baiting strategies, IPM

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INTRODUCTION

A new class of rodenticides became available in the 1940s with the introduction of warfarin by the Wisconsin Alumni Research Foundation, Madison, Wisconsin. The advantage of warfarin (and closely related hydroxycoumarin compounds) was that it was effective in killing rats and mice with a relatively low dose when consumed regularly over a period of several days. Further, a large amount of warfarin bait consumed at one time would not effectively kill; thus, this new rodenticide had a built-in safety factor regarding non-target species such as cats, dogs, and children. Proper baiting procedures should prevent access to baits by non-target species, and certainly should prevent the repeated ingestion necessary for intoxication. In essence, warfarin was a product that was close to that elusive "magic bullet" of pest management. An unfortunate outcome of this discovery was that rodent control became largely an issue of chemical intervention with less emphasis placed on public health education, housekeeping, storage practices, sanitation, and exclusion (proofing and stoppage). Not surprisingly, anticoagulants have been the most preferred rodenticides since World War II.

The identification of warfarin resistance in the United States (known in Europe since 1958) in *Rattus norvegicus* in North Carolina in 1971, and later in *Mus musculus* and *Rattus rattus* (Jackson et al. 1985), heralded in another shift in rodent pest mitigation. This shift was the industry's increased interest in the development of more toxic anticoagulant products (e.g., brodifacoum, bromadiolone) capable of killing with one or a few feedings. Unfortunately, the more potent anticoagulants also have greater risks to non-target species. Development of the more toxic products, both anticoagulant (e.g., difethialone) and non-anticoagulant (e.g., bromethalin), continues today. While not remarkable in thoroughness nor consistency, there is an increasing trend in some sectors of the pest management industry favoring comprehensive approaches (i.e., integrated pest management [IPM]) which: emphasize educating clients and reducing causative conditions; diminishing the role of toxicants; and, when necessary, using chemical products of the least practical toxicity (Frantz and Davis 1991). Of course, concomitant with changes in the industry are necessary changes in the public's perception of what to expect in an IPM program.

In this presentation, the authors reexamine the definition of "anticoagulant resistance" in Norway rats (*Rattus norvegicus*) and how rodent control programs might counteract anticoagulant resistance. In fact, warfarin products themselves may be more useful than was thought during the heyday of "super rat" preachments. Nationwide warfarin resistance data are examined from the New York State Department of

Health's former Rodent Control Evaluation Laboratory (a technical adjunct to the Centers for Disease Control and Prevention's former Urban Rat Control Program).

MATERIALS AND METHODS

Animals

All animals used in this study were warfarin-resistant Norway rats (*Rattus norvegicus*) belonging to one of three different source groups. An animal was "resistant" if it had survived the standard warfarin resistance screening test; that is, it survived six days on .005% warfarin bait, nine days on placebo (post-test), and had consumed a total warfarin dosage of at least 12 mg/kg (Brooks and Bowerman 1973, 1974).

Two source groups were comprised of wild-trapped rats from project cities that had been sampled during the nationwide anticoagulant rodenticide resistance surveillance program, a service conducted in conjunction with the federally funded CDC Urban Rat Control Program (Frantz and Padula 1980). One group, mixed source, contained rats from 23 project cities of the United States and Puerto Rico where resistance levels in the sampled rat populations ranged from 1.6% to 25.0%. The second group of wild rats came from only the Chicago, Illinois project where resistance levels in two different sampled populations were 59.7% and 76.2%.

The third group of rats were all F_1 offspring of various combinations of wild-trapped Chicago rats, some of which had been identified as resistant (through the screening test) and others which were of unknown susceptibility (untested) to warfarin. Of 106 of the F_1 Chicago offspring, 76.4% proved to be warfarin resistant upon initial warfarin screening. This offspring group provided age-related data for comparison with the wild-trapped groups which were of unknown age when they arrived at the laboratory.

Test Procedures

All wild-trapped rats were singly caged in mesh-floored cages within about 24 hours of their arrival at the laboratory and held for a minimum of three weeks before being screened for anticoagulant rodenticide resistance (as described in Frantz and Padula 1980). All F_1 Chicago offspring were weaned and singly caged at an age of approximately four weeks; they were then held until about 150 days of age before being screened for resistance.

During the period before anticoagulant resistance screening, all animals received a diet of laboratory food pellets (Wayne Lab Blox, Allied Mills, Inc., Libertyville, Illinois) which contained "added" vitamin K. The overall vitamin K activity of Lab Blox is unknown, but its use may add to the homogeneity of the test animals by minimizing variations in vitamin K status, particularly of wild-trapped animals. Both food and water were provided *ad libitum*. At pre-selection, one week before initiation of pre-test, animals received lab meal (Purina 5001 Lab Chow, Ralston Purina Co., St. Louis, Missouri), containing no added vitamin K. Later, this meal was used as the pre-test diet and then as the base for the warfarin bait in each test or retest.

Pre-selection and selection criteria were that animals were in a healthy condition, not pregnant, without obvious wounds or other pathologies, and weighed at least 150 grams (Frantz and Padula 1980). These criteria are essentially the same as given in the standard WHO procedure (1970) and in Jackson et al. (1975), and were used before each screening test or re-test procedure. The pre-test, test and post-test procedures were essentially the same as described in Frantz and Padula (1980) and are presented as an algorithm in Figure 1; resistance criteria also remained unchanged from the authors' previous work.

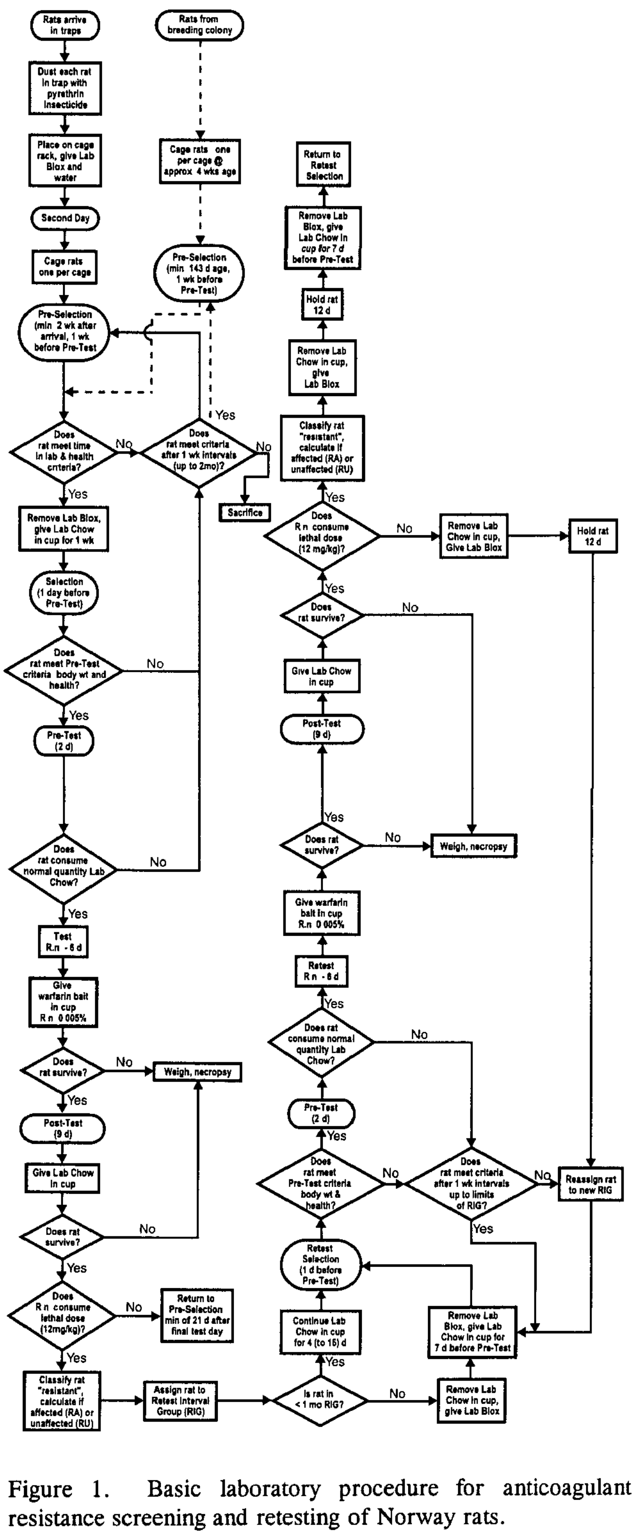

Figure 1. Basic laboratory procedure for anticoagulant resistance screening and retesting of Norway rats.

As resistant animals were identified by the standard screening procedure, they were assigned to one of three retest interval groups (RIG)—or recovery interval groups—depending on the interval between the last day an animal received warfarin bait in the screening test and the first day it was to receive its second laboratory exposure to warfarin in the first retest (retest$_1$) procedure. The three retest interval groups were defined as follows:

Retest Interval Group (RIG)	Days Since Last Received Warfarin Bait Limits	Days Since Last Received Warfarin Bait Range Used
<1 month	15-27	15-27
1-2 months	28-59	28-50
>6 months	180-730	196-633

Once an animal was in the time range of its assigned RIG, it was again tested (i.e., re-tested) by the same procedure as in the standard warfarin resistance screening (see Figure 1). Note that procedural differences occur just prior to Retest Selection due to the necessary timing requirements of the RIGs. That is, in the <1 month group, the authors wanted to retest at 15 days whenever possible; but there was not sufficient time for a nine day post-test, seven days on Lab Chow before pre-test$_2$, and a two day pre-test$_2$—a total of 18 days. Therefore, the three steps were merged; in essence, the post-test$_1$ remained nine days, and pre-test$_2$ remained two days, but the time between these steps was reduced to four days. If, for some reason, an animal did not meet basic test criteria (body weight, health, etc.) (see Frantz and Padula 1980) at that time, it was held for another week or up to 16 days. After 16 days, the animal was reassigned to a RIG with a longer interval between screening and retest. Rats assigned to the other two RIGs which did not meet criteria were treated similarly.

Many animals surviving the retest$_1$ were placed back on a Lab Blox diet, held 12 days, returned to Lab Chow for nine days (seven days + two day pre-test), and then retested repeatedly (e.g., retest$_2$, retest$_3$, retest$_4$, etc.) until they died (to be reported elsewhere). For all retests after the first, the interval between warfarin exposures was fixed at 30 days. Note that some animals surviving the first retest (retest$_1$) were removed from this study for use in other tests requiring resistant rats.

RESULTS AND DISCUSSION

In the <1 month category, 52 rats from mixed sources (excluding Chicago) were retested with 59.6% (31/52) mortality; 18.0% (11/61) mortality resulted when this test was repeated with Chicago-trapped rats (see Table 1). In the second category of 1 to 2 months (see Table 1), 61.2% (30/49) of the mixed-source rats died, whereas 14.7% (10/68) of the Chicago rats died. Repeating this test (1 to 2 month RIG) with 17 of the F$_1$ Chicago offspring resulted in a mortality of 5.9% (1/17). In the third RIG category of >6 months (see Table 1), 47 mixed-source rats were retested with 83.0% (39/47) mortality; only six Chicago-trapped rats were retested and one died (16.7%).

While test results beyond retest$_1$ will be discussed elsewhere, it is worth noting that few mixed-source rats survived retest$_3$. That is, most animals of mixed-source origin (excluding Chicago) tested from each of the three RIG categories succumbed upon their fourth exposure to warfarin bait in no-choice tests. Chicago-trapped rats in the <1 month, 1 to 2 month, and >6 month groups commonly survived retest$_8$, retest$_{10}$, and retest$_3$, respectively. Thus, some Chicago rats survived 11 lethal doses of warfarin rodenticide, the last 10 of which were consumed at 30 day intervals.

From these data, it appears that mortality for most rats is not significantly affected by the recovery time interval (RIG) for at least the categories of <1 month and 1 to 2 months. The high mortality among mixed-source rats in the >6 month category may be age related. For Chicago rats in this latter category, not enough data are available for analysis. Source (geographic origin), however, is clearly important. Upon first retest, Chicago rats have a significantly greater probability of survival than those animals from mixed sources.

Thus, the most significant finding of these data is that "resistant" (as by standard WHO screening measures) Norway rats from many geographic locations are likely to die upon re-exposure to warfarin, the very product which is used to identify or define their resistance. That is, in a baiting program with warfarin it appears that it should be possible to continue to effectively use warfarin bait *if* a time period of at least two or more weeks without warfarin exposure is allowed between baiting cycles. In fact, the two-week hiatus would be a good time to complete more sustaining, non-toxic interventions such as public health education, housekeeping, storage practices, sanitation, and exclusion (proofing and stoppage). Even in the Chicago area, or other areas that might be identified with similar anticoagulant resistance characteristics, rats will not be "resistant" to such non-toxic interventions that are a significant part of a properly conducted IPM program.

While it should be somewhat easier for rats to consume a normally lethal dose of warfarin in the field situation because of the higher warfarin concentration (.025% in most commercial baits vs .005% in no-choice laboratory tests), bait acceptance might be negatively affected by the higher warfarin concentration and by the availability of other food materials (Jackson et al. 1975). Thus, the need for interventions to limit food resources (e.g., sanitation) is underscored. The uninterrupted use of warfarin baits over long periods of time should be discouraged because such practices would select for resistance (behavioral or other).

A second issue of importance raised by these data is how to define the "resistance" of rats being utilized in efficacy tests of rodenticidal products designed to kill warfarin resistant rats. If a product is tested against "resistant" rats from many geographic areas, the efficacy results become unclear when more than half of such rats might have succumbed to warfarin as shown with the mixed-source test group. Repeated baiting cycles using warfarin (with 30-day intervals of no warfarin) might well

Table 1. Results of resistant[a] wild Norway rats' (*Rattus norvegicus*) second exposure (no-choice feeding test) to .005% warfarin bait.

Source of Rats	Time Interval to Retest$_1$ (months[b])	Rats Retested (Number)	Mortality at Retest$_1$ (Percent)
Mixed Wild-Trapped[c]	<1	52	59.6
	1-2	49	61.2
	>6	47	83.0
Chicago Wild-Trapped	<1	61	18.0
	1-2	68	14.7
	>6	6	16.7
Chicago Lab-Bred[d]	1-2	17	5.9

[a]As determined by the standard warfarin screening test (Brooks and Bowerman 1973 and 1974)
[b]Number of months since exposed to warfarin bait
[c]Excluding Chicago Wild-Trapped rats
[d]F_1 offspring of Chicago Wild-Trapped rats

effectively reduce most rat populations without the adverse consequence of increased risk for non-target species intoxication.

CONCLUSIONS

These data raise interesting questions regarding the significance of the warfarin resistance "problem" and how to effectively conduct efficacy tests for products designed to counteract warfarin resistance. Although many details remain to be clarified, these studies support the need to emphasize a non-chemical strategy for rodent control efforts. Environmental sanitation and rat proofing would go far to eliminate food and harborage resources and thus curb breeding activity—affecting all animals in the population as demonstrated decades ago by Davis (1950), Holloway (1947), Orgain and Schein (1953), and others. Elimination of the food alternatives would also increase bait acceptance whenever the chemical strategy is necessary. Under environmentally improved conditions, it should be possible to kill resistant animals in most localities with the standard anticoagulants (including warfarin) and adjusted baiting schedules, rather than switching to rodenticide baits which have a higher risk to humans, pets, livestock, and/or wildlife.

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RAT MANAGEMENT FOR ENDANGERED SPECIES PROTECTION IN THE U.S. VIRGIN ISLANDS

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ABSTRACT: Introduced roof rats (*Rattus rattus*) pose a substantial threat to the fauna and flora of many tropical islands. In the Caribbean, there is concern about rat impacts to several endangered species, including the Atlantic hawksbill sea turtle (*Eretmochelys imbricata*) and the least tern (*Sterna antillarum*). The authors surveyed the rat population on Buck Island, Buck Island Reef National Monument, U.S. Virgin Islands in February 1998. Based on three nights of trapping, rats were of low to moderate abundance during the sampling period when compared to results from other Caribbean islands. The impact of rats on native vegetation was evident over the entire island. A rat management program was proposed using anticoagulant rodenticide baits in bait boxes in and around the two picnic areas on the island. Once an appropriate rodenticide registration is obtained, the baiting program can be extended to include the rest of the island. The eventual eradication of rats from Buck Island will not only provide relief for several endangered species nesting on the island, but will set the stage for the reintroduction of the endangered St. Croix ground lizard (*Ameiva polops*).

KEY WORDS: endangered species, least tern, *Rattus rattus*, rodent damage, rodenticide, roof rat, sea turtle, wildlife management

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INTRODUCTION

At the request of the National Park Service (NPS), Wildlife Services (WS) conducted a site visit to the U.S. Virgin Islands to assess damage by rats to resources at Buck Island Reef National Monument and to assist the NPS in designing a rat management program. WS' biologists visited the U.S. Virgin Islands National Park and Buck Island on February 15 to 21, 1998. The visit included meetings in St. Croix and fieldwork on Buck Island. Personnel of several agencies participated in the meetings. In this report the authors provide an overview of the situation, some results of the rat population assessment, and a proposal for rat management on Buck Island.

OVERVIEW OF SITUATION

The overview of the situation on Buck Island is based on: 1) a review of literature on rats on islands and reports provided by the NPS; 2) a brief site visit to the island in February; and 3) the authors' experience in other similar situations. Buck Island is about 1.5 miles offshore of the northeast coast of St. Croix in the Caribbean Sea and comprises about 180 acres, rising from sea level to about 340 feet in elevation. The island has no permanent sources of freshwater and is covered with a dry, tropical deciduous forest. Although the island is uninhabited and managed as part of the NPS system, it has a history of human habitation that involved various land uses and activities: settlement with structures, farming, tree harvest, human-caused fires, and deliberate, as well as, accidental introductions of plants and animals. Roof rats (*Rattus rattus*) were accidently introduced to Buck Island via ships and cargo, probably in the early years of European exploration and settlement of North America. Roof rats, along with two other European rodent species, Norway rat (*Rattus norvegicus*) and house mouse (*Mus musculus*), have achieved worldwide distribution in this manner. The close association of these prolific, adaptable species with humans and their ready ability to use various human-provided sources of food has resulted in the use of the term "commensal rodents." The numerous and serious problems caused by commensal rodents (loss and contamination of food stuffs, damage to property, and human health hazards) has been well documented and control has been aggressively pursued worldwide (Witmer et al. 1995). Additionally, in tropical areas, commensal rodents have caused major disruption of ecosystems, often reducing biodiversity and putting native species at risk of extirpation (Buckle et al. 1992; Key et al. 1996; Wace 1986). The fauna of many islands has evolved with only a minor (or no) mammalian component and relatively few—if any—predatory species. As such, rats—with their diversified and voracious feeding habits and ability to reproduce rapidly and achieve high densities—can put many species (both plants and animals) at risk. Indeed, high extinction rates on islands have often been attributed to introduced mammalian species, especially rats (Burger and Gochfeld 1994; Whitaker 1978).

A number of species, both floral and faunal, are at risk on Buck Island. Rats may affect island faunas by preying on eggs, young, or adults, and by competing with them for resources such as food or nest sites (Campbell

1989). The NPS has documented impacts to several threatened or endangered species: sea turtles (and in particular, the Atlantic hawksbill turtle [*Eretmochelys imbricata*]) and least tern [*Sterna antillarum*]. Although the authors were not on the island during the nesting season of these species, NPS biologists have documented predation on eggs and hatchlings of these species (e.g., Small 1982). This is consistent with published scientific literature. For example, Atkinson (1985) presented many cases of roof rat predation on oceanic island birds. Roof rats may have been responsible for the 100% mortality reported for two separate roseate tern (*Sterna dougallii*) colonies on Little Saint James Island in the Caribbean (Dewey and Nellis 1980). Endangered brown pelicans (*Pelecanus occidentalis*) also nest on Buck Island, but rats are generally not considered a threat to them (Anderson et al. 1989).

Because rats are omnivores, a number of plant species may also be at risk. The native flora of Buck Island has already been affected by various human activities such as grazing by goats, and especially the introduction of non-native plant species that aggressively compete with native species for light, moisture, nutrients, and space (Woodbury and Little 1976). Drought and periodic hurricanes make the perpetuation of some native plant species even more difficult. Botanical surveys have documented extensive damage to native (and non-native) plants by rats (Gibney 1996; Key et al. 1996). This was observed, as well, on the site visit. Rat damage was commonly observed on cactus, trees, and shrubs all along the trail system, including these plant species: *Adelia ricinella*, *Bourreria succulenta*, *Cephalocerus royenii*, *Cordia rickseckerii*, *Guaiacum officinale*, *Melocactus intortus*, and *Tournefortia volubilis*. The level of damage may be indicative of a moderate density of rodents using plants to obtain moisture on an island with no permanent freshwater.

The NPS and the U.S. Fish and Wildlife Service (FWS) plan to reintroduce the endangered St. Croix ground lizard (*Ameiva polops*) to Buck Island as part of the FWS recovery plan for that species (USFWS 1984). The island provides a primary recovery area for this species which currently only occurs on two much smaller Cays (Protestant Cay, about 7 acres, and Green Cay, about 14 acres). Both of these Cays also have rats, and Protestant Cay is privately owned and developed for tourism; this situation puts the St. Croix ground lizard at great risk of extinction. Both NPS and FWS personnel realize that the value of Buck Island as a reintroduction site is severely reduced by the presence of rats on the island. The impacts of commensal rodents on reptiles and other members of island faunas have been well documented (Campbell 1989; Rivero 1978; Whitaker 1978). In addition to direct predation, rats can reduce habitat quality for lizards by removing substantial amounts of ground cover (e.g., litter, vegetation).

As has occurred on many tropical islands, mongoose (*Herpestes auropunctatus*) were introduced to Buck Island in the late 1800s for the purpose of rat population reduction. It is now known that this is rarely successful, in part because mongoose are primarily diurnal while rats are primarily nocturnal. Mongoose do prey upon rats, but have rarely, if ever, been shown to cause a significant reduction in rat density. Conversely, mongoose are generalist predators, feeding on a variety of vertebrate and invertebrate species (Coblentz and Coblentz 1985). As such, they have caused significant impacts to the native fauna of islands to which they have been introduced. Mongooses have been strongly implicated in the extirpation of the St. Croix ground lizard from St. Croix and Buck Island (Philobosin and Ruibal 1971). The NPS began an aggressive mongoose eradication program on Buck Island in the mid-1980s, using live traps. This resulted in a large reduction in the mongoose population on the island, but the NPS has suspected that a few mongoose remain, based on occasional observation of tracks or, in one case, the recovery of a carcass. The authors observed what appeared to be a fresh set of mongoose tracks along the west beach during their site visit. Protection of the native fauna and the re-establishment of a population of the St. Croix ground lizard on Buck Island will require the prevention of mongoose population expansion (Meier et al. 1990).

Rats have not been controlled on Buck Island in recent history, short of some minor trapping and removal activities by NPS personnel during turtle nesting season. It appears that this effort was very limited and occurred because of the incessant harassment not only of sea turtles, but also of nesting survey personnel. Rats not only feed upon turtle eggs and hatchlings, but also harass female turtles attempting to select a nest site. NPS personnel observed that some females abandoned their nesting attempt and returned to the sea. Losses (of eggs or hatchlings) to as many as one-third of the hawksbill turtle nests being monitored has been documented by NPS personnel in recent years. Rat predation on sea turtle eggs at Buck Island is not a new problem; Small (1982) reported the destruction of about 23% of hawksbill turtle eggs and hatchlings in 1981.

Least tern eggs and hatchlings are also consumed by rats. Predation has been documented by NPS personnel in recent years and the nesting attempt by about 20 adult terns in 1997 was abandoned before eggs were laid. Predation by introduced rats has been implicated in the decline in many populations of island-nesting birds in the Caribbean and elsewhere (Burger and Gochfeld 1994).

There is also a human health risk from the rats on Buck Island. There have been cases of tick-borne relapsing fever (caused by a *Borrelia* spirochete bacteria) in humans living in the Virgin Islands (Flanigan et al. 1991) and the tick species responsible (*Ornithodoros puertoricensis*) for transmitting the spirochetes to humans have been found on rats collected on Buck Island. In theory, the risk of tick bites to humans on the island is low because of the nocturnal activity patterns of both rats and these ticks, and because there is no overnight lodging by humans on Buck Island. However, day visitors to the island have been harassed by rats, and sea turtle research personnel, working nights on Buck Island, have been even bitten by rats.

RAT POPULATION ASSESSMENT

On the authors' preliminary survey of Buck Island, some rats were observed during daylight hours, especially in the west beach picnic area. Some ground burrow entrances and many cases of damaged plants of various species were also observed. Rat tracks were common along beach-rocky slope interfaces. Field personnel were instructed in the identification of poisonous plants (in particular, manchineel trees [*Hippomane mancinella*] and Christmas-bush [*Comocladia dodonaea*]); this would be especially important for personnel safety during subsequent night work.

It was decided to use a rat trapping protocol that had been used on other Caribbean islands (Campbell 1989). This allowed the authors to work efficiently and to make a relative comparison of the Buck Island results with those from other islands. The existing trail system was used, and 11 to 19 rat snap traps were placed along each of three trap lines. Traps were secured to the side of a tree about 10 to 20 inches above the ground surface with a trap placed every 15 feet along the trail. The three trap lines covered a variety of habitats, slopes, and elevations on the island: 1) the low-lying west beach area; 2) the island ridge line west from the Coast Guard; and 3) a line ascending the south-central trail from the Diedrichs picnic area.

Traps were baited with a mixture of rolled oats and peanut butter and set just before sunset on each of three consecutive nights. The traps were checked at one-hour intervals from 7 p.m. to 10 p.m. Trapped rats were labelled and bagged for later examination and the trap reset. At the last check (10 p.m.) of each night, the traps were sprung and left in place for the next night. Reflector tape on traps and pink plastic flagging on a nearby tree or bush facilitated the locating of traps at night. All traps were removed at the end after the last check on the third night. NPS personnel assisted in establishing and running the trap lines; this provided them with the knowledge and experience needed to monitor the rat population in the future.

Rats were very commonly encountered during the night work, especially at the picnic areas where they were very unwary. Eighty rats were captured over the three-night period (Table 1). More rats were captured from the west beach area (52) than either the ridgeline area (12) or the ascending south-central trail area (16). The capture rate did not decline by the third night, and because trapping was only done for three nights, it is not known how many more nights of trapping would have been needed to see a substantial decline in captures. When the capture data were adjusted for sprung traps, as recommended by Nelson and Clark (1973) and Innes (1990), trap success indices (on a scale of 0 to 100) ranging from 11.0 to 29.3 were obtained. When compared to the results of previous trapping efforts on other Caribbean islands where indices ranged from 0 to 90 (Campbell 1989), the Buck Island results suggest a low to moderate rat population abundance. Because the rat population was sampled at one brief point in time, direct comparisons with other study results may not be appropriate. Additionally, it is noted that rat densities on islands would be greatly effected by amounts of vegetation and precipitation (Atkinson 1985; Jackson et al. 1987). As such, the Buck Island rat population could potentially irrupt to a much higher density with the onset of the rainy season. In any case, this rat population data provide a baseline that could be used to monitor changes in rat abundance. Both sexes and age classes (juvenile and adult) were represented in the rat sample from Buck Island. There was a nearly equal ratio of male-to-female captures with slightly more females captured. Most females (>90%) were sexually mature, as were most (>90%) males. The low total proportion of juveniles in the population (8.8%) suggests low reproductive activity; it is also possible that a high rate of juvenile mortality is occurring. Reproductive activity could be quickly initiated with rainfall and greater food availability. The lengths of male and female rats were similar to those reported for other roof rat populations (Campbell 1989; Jackson 1982); however, the average weights of Buck Island rats were somewhat lower for both males and females, suggesting that the population may be nutritionally stressed. There was some evidence of fighting among the rats, based on lacerations and scars.

RAT MANAGEMENT

A wildlife damage management program should be based on a thorough understanding of: 1) the biology and ecology of the problem species; 2) the type, amount, and timing of damage; 3) management options and methods available; and 4) the relevant laws and regulations. Most rodent damage management programs use a combination of methods, including: 1) exclusion or rodent-proofing; 2) habitat modification and sanitation; and 3) toxicants and/or traps. Other methods (increasing predation, shooting, fumigants) are less often used or are ineffective (frightening devices, repellents). The basic biology and ecology of roof rats and management methods are presented in Buckle and Smith (1994), Jackson (1982), Marsh (1994), Meehan (1984), and Storer (1962).

Even with the brief, one-point-in-time assessment of the Buck Island situation, it would appear that the sizeable rat population is impacting numerous floral and faunal resources. It would also appear that the proposed reintroduction of the St. Croix ground lizard to the island would be jeopardized by the rat population. The authors were initially contacted by the NPS because they wanted assistance in designing a rat eradication program. Rat eradication is a worthy goal and would provide a permanent solution to the problem. Rats have been successfully eradicated from a number of islands around the world (Moors 1984; Morgan et al. 1996; Taylor and Thomas 1993). In the Caribbean, rat eradication efforts have been completed on several islands and efforts on additional islands are underway (D. Nellis, U.S. Virgin Islands Bureau of Wildlife, pers. comm.). Once eradicated, a relatively low-keyed monitoring effort would be used to determine if reinvasion has occurred. A prompt response with appropriate measures if reinvasion occurs, while rodent numbers are very low, may preclude the development of another serious situation as now exists on Buck Island.

While rat eradication from islands can be achieved, it requires a concerted, sustained effort with adequate resources. In general, rodenticides are used because they are more efficient, less costly, and more effective in removing large numbers of rats than are live or kill traps. Additionally, a portion of any rat population is usually "trap shy." It should be noted, however, that a rodent population may become "bait shy" (this usually occurs with acute toxicants) or resistant to the toxicant (although

Table 1. Assessment of Buck Island rat population, based on three nights of trapping, February 18-20, 1998.

Transect (No. of Traps)	Rats Captured by Date 2/18	2/19	2/20	Total	Mean Corrected Trap Success[a] (SE)
West Beach (19)	16	13	23	52	29.26 (4.07)
Diedrichs (15)	3	10	3	16	11.97 (4.61)
Tower (11)	0	9	3	12	10.97 (4.67)
Totals	19	32	29	80	

[a]An index of abundance; values can vary from 0 (no captures) to 100 (very high capture success). This is a measure of captures per trap-effort (CE), adjusted for sprung or nonfunctional traps, according to the formula: CE=Ax100/(TU-IS/2), described in Innes (1990) and Nelson and Clark (1973).

Sex Ratio of Population	Proportion of Juveniles in Population
Males: n = 37	Juvenile Males: 3/37 = 8.1%
Females: n = 43	Juvenile Females: 4/43 = 9.3%
M:F Ratio = 1:1.16	Total Juveniles: 7/80 = 8.8%

Morphological Data on Population

Attribute	Males (n = 37) Mean	SE	Females (n = 42) Mean	SE
Body Weight (g)	147.6	6.3	139.9	5.7
Total Length (mm)	396.6	5.2	387.2	5.6
Body Length (mm)	182.4	2.7	176.8	3.1
Tail Length (mm)	214.2	2.9	210.4	3.0

rare, this has occurred with some anticoagulants); in either case, an alternate rodenticide should then be used. Numerous types of rodenticides are available and have been used for the management or eradication of commensal rodents. Both acute and chronic (anticoagulant) types are available. In general, anticoagulants are preferred because: 1) they can be used effectively in very low concentrations; 2) there is an antidote (vitamin K) available; and 3) secondary hazards are usually lower than for acute toxicants. The two anticoagulants most commonly used in the United States are chlorophacinone and diphacinone.

In general, the use of registered rodenticides is allowed in or within 150 feet of man-made structures. To use rodenticides in other areas would require a: 1) federal [Section 3]; 2) state or local needs [Section 24c]; or 3) emergency use [Section 18] registration as per the Federal Insecticide, Fungicide, and Rodenticide Act and as administered by the U.S. Environmental Protection Agency (EPA). Because emergency use registrations are usually issued for a one-time use, it would be better to obtain a Section 3 or 24c registration. The authors were not able to ascertain, during their brief visit, what rodenticide registrations—if any—are available for the Virgin Islands. NPS personnel will need to contact the NPS Integrated Pest Management (IPM) specialist, the EPA Region 2 Office, or the Virgin Islands Department of Planning and Natural Resources.

Rat eradication would be most efficiently achieved with the aerial application of bait blocks. Obtaining a registration for such an operation may be difficult, however, because of environmental concerns and potential hazards to nontarget species. The use of bait boxes would reduce the potential hazards, but results in additional expense and labor. To be effective, baits should be distributed over the entire island in a grid-like pattern with bait blocks/boxes about every 100 to 150 feet. Bait boxes could be placed in trees or on the ground. A pattern of trails would need to be established for bait placement and maintenance, similar to what was done for the mongoose trapping program of the 1980s. Once initiated, the baiting operation would probably require several months to complete. After placement, baits would need to be checked and replaced as needed. Initially, this would probably be every few days, but would drop to about once per week after the rat population was greatly reduced. Typically, baits are maintained for weeks after all consumption has virtually stopped to help assure that all rats have been eliminated. Because of limited personnel to dedicate to this effort, it is recommended that the NPS consider subcontracting out this work to an appropriate agency or party. To accomplish this goal an EPA registration for the use of rodenticides for conservation purposes on wild lands would be required.

Before the funding, materials, personnel, and permits are secured for a rat eradication program—and in the event that this level of effort is never achieved—it is recommended that the NPS begin a rat management program as part of a tiered approach. The authors envision these three tiers:

1. Use of bait boxes within 150 feet of the two picnic areas. The existing structures make this readily possible with a minimum of permit requirements. This approach would focus on the high rat density areas and would most specifically address rat-human encounters.
2. Expansion of Tier 1 to include bait boxes distributed over an area not to exceed 10 acres that includes as much of the west beach turtle nesting area as possible. An experimental use permit (Section 5) is more easily obtained if the area treated is <10 acres. This approach should provide relief to nesting turtles and would allow the NPS to monitor the rat population in the area *and* turtle nesting success, as well as to address and correct any problems with the baiting program before an island-wide eradication attempt is undertaken. This area could perhaps include the least tern nesting beach as well.
3. An island-wide eradication effort as described above. If, and when, the appropriate registration is obtained and logistical arrangements are in place, this effort could proceed. Only this Tier 3 action has the potential to resolve the rat problem on Buck Island on a permanent basis; the other two tiers would require annual effort and expense for an indefinite time period.

It is difficult to accurately estimate the implementation cost for each tier. Expenses could be kept lower through the cooperation and interaction of several agencies or parties and the use of volunteers. Taylor and Thomas (1993) estimated that it cost about $120 per acre to eliminate rats from a 425 acre island off the shore of New Zealand in 1988-89; they relied on volunteers for much of the labor. This would correspond to a cost of about $22,000 (1990 prices) for the same intensity effort on the 180 acre Buck Island. It is recommended, however, that the NPS not rely on volunteer effort for this important project. Salaries, and the need for a project vehicle on St. Croix, increase the project cost substantially over the New Zealand project even with the conversion of their costs to 1998 dollars. Information on the suppliers of materials that would be needed for any level of rat management were provided by Hygnstrom and Hafer (1994).

The NPS has already initiated a public education program regarding the rats and their impacts on Buck Island. This effort should be continued and even expanded. The goals of the program should not only be to educate the public, but to gain public support for a vigorous, sustained rat management or eradication program. Other elements of an integrated pest management strategy need to be implemented as well, especially with the Tier 1 and 2 approaches which involve a protracted management program. Trash must be contained and regularly removed from the island. Consideration should be given to not allowing concessionaires to feed visitors to Buck Island. Buildings and structures should be inspected and modified, as needed, to minimize or prevent rat access and damage. A routine rat monitoring program should be established. The current monitoring and documentation of rat damage to other resources should continue and, preferably, be expanded to more fully quantify the problems and provide additional insight into the timing and location of damage and into the association of damage with other factors (e.g., storms, drought, human activities). Monitoring also provides a feedback mechanism so that the rat management program can be revised (expanded, downgraded, or eliminated) periodically, as needed.

This assessment of the rat situation on Buck Island derives from one brief visit during one week in February. As such, statements and recommendations are of a preliminary nature. A more thorough assessment would allow better definition of the situation and more confidence in those statements and recommendations.

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STATE AGENCY RESPONSE TO NUISANCE WILDLIFE CONTROL OPERATOR OVERSIGHT

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ABSTRACT: An 18-question survey was sent to all state wildlife agency directors in an attempt to evaluate state wildlife agencies' response to administrative oversight of nuisance wildlife control operators (NWCO). Forty-four (88%) of the state wildlife agencies responded to the survey. Almost every state agency responding believes they should promote the growth and privatization of the NWCO industry. They also believe that their agency should provide administrative oversight. There were descrepancies in what agency personnel believe constitute oversight versus what policies are actually implemented. Although most agencies believe NWCO should be licensed, only 56% of states actually require licensing. Most agencies responding believe NWCO should be required to complete an educational program and a written examination prior to receiving a license, currently only 22% require some form of education prior to obtaining a license, and 15% require an examination prior to obtaining a license. Sixty percent of agencies believe NWCO should show evidence of financial responsibility and only 5% of states actually require NWCO to have liability insurance or post a surety bond. Fifty-six percent of the states require NWCO to submit written reports that document the number of each animal species captured (51%), disposition of animals (44%), location of capture animals (34%), release site information (22%), condition of captured animal (7%), and euthanization method (5%). Most states allow nuisance wildlife to be released on both private (90%) and public land (71%). Approximately one-third of agencies have changed laws, policies, or regulations regarding NWCO and 47% of these changes are perceived to be more restrictive of NWCO activities. Most state agencies (78%) allow relocation of nuisance wildlife, but 17% of the states have restrictions on what species can be relocated. The primary reason for not allowing relocation of nuisance wildlife are disease (100%), impacts to resident wildlife populations (45%), humane reasons (18%) and a lack of suitable release sites (9%). These results show that state agencies believe they should encourage the growth and privatization of NWCO industry and that they should maintain administrative oversight.

KEY WORDS: nuisance wildlife, education, licensing, policy, euthanization, raccoons, squirrels.

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INTRODUCTION

There has been rapid growth and privatization of the nuisance wildlife control field. With this increased expansion are concerns about the role of state wildlife agencies in ensuring nuisance wildlife control operators (NWCO) competency and professionalism, impacts of relocation on translocated and resident wildlife populations, and animal and human welfare and safety issues. Furthermore, state wildlife agencies have frequently demonstrated a reluctance to work with wildlife related industries (e.g., aquaculture) and many NWCO perceive the state agency to be oppressive to growth (Messmer, pers. comm.). Brammer et al. (1994) called for policies that would allow for the continued development of the NWCO industry while maintaining state wildlife agency oversight. There appears to be a need and interest on the part of state agencies in developing rules to guide and oversee NWCO (LaVine et al. 1996), especially because there is variation in how states administer NWCO programs (Craven and Nosek 1992; Brammer et al. 1994; LaVine et al. 1996). In response to this expressed need, Barnes (1997) proposed a model program designed to allow for the growth of NWCO and state agencies to monitor and guide this growth. He proposed that state agencies encourage the privatization of NWCO by formalizing it as a legitimate business and requiring all individuals, companies, or other entities to complete an educational program with testing prior to obtaining a license. He also recommended the formation of an advisory group to help the agency provide oversight, educational requirements, continuing education requirements, and other pertinent topics. The purpose of this study was to evaluate state wildlife agency response to Barnes' (1997) proposed NWCO oversight model.

METHODS

An introductory letter, 18-question survey, and postage paid envelope was mailed to all 50 state wildlife division directors on August 20, 1997. Survey questions were designed to identify actual policies related to NWCO activities and to agency beliefs, attitudes, or opinions regarding components of the proposed oversight model (Barnes 1997). Because most NWCO desire to live-capture and release nuisance wildlife (Clark 1992; Barnes 1995a, b), a subset of questions was asked regarding agency policy on the translocation of wildlife. Most questions required a yes/no answer. There were a series of questions designed to evaluate what an agency "perceived" as an appropriate NWCO policy versus the actual policy administered by the agency. The author tabulated frequency or percentage for all questions.

RESULTS AND DISCUSSION

Forty-four (88%) of the state wildlife agencies returned the survey. This response rate is similar to past NWCO surveys of state agenices (Branner et al. 1994; LaVine et al. 1996). States from every region of the country responded to the survey, and the majority of states not responding to the survey were in the Great Plains region. One possible explanation for this might be the lack of NWCOs in this area because there are few large metropolitan areas, and rural landowners or homeowners solve their own problems (Curtis et al. 1995). Hence, these state agencies may be insulated from many of the issues surrounding this topic.

Most state wildlife agencies believe that they should promote the growth and privatization of the NWCO industry (93%) and that their agency should provide administrative oversight (95%) in concurrence with recommendations of Barnes (1997). When asked specific questions regarding licensing, education, and financial rsponsibility, there was a large difference between what agencies perceive to be good policy versus existing policy (Table 1). Most agencies believe they should require NWCO to have a license to operate and that they should have some form of educational requirement and examination prior to licensing. However, only 56% require a license which is a 10% increase in states that require a NWCO license during the past three years (LaVine et al. 1996). Few agencies (less than 25%) require any form of education, training, or examination prior to licensing (Table 1). LaVine et al. (1996) reported that 47% of states do not have any prerequisites for becoming a NWCO. This difference may be a result of the questioning because they asked if a state had any prerequisites that could include a trapper training course, NWCO examination, education or experience, investigation by agency personnel, or application review process. The results concerning continuing education and proof of financial responsibility (liability insurance or surety bond) indicated that approximately two-thirds of the state agencies believed they should require these of NWCO (Table 1). Less than 5% of agencies actually require continuing education or proof of financial responsibility which is comparable to data presented by LaVine et al. (1996). The small number of agencies that require proof of financial responsibility is surprising because by licensing a NWCO, they become an agent or representative of the state (S. Shupe, KDFWR lawyer, pers. comm.) and both the NWCO and the state then assume a liability risk. This risk could be greatly reduced by requiring NWCO to have liability insurance or a surety bond (S. Shupe, pers. comm.).

Fifty-six percent of the states require NWCO to provide written reports to their agency. The types of information required on these reports include: number of each animal species captured (91%), disposition of captured animals (78%), location of captured species (61%), the release site of captured species (39%), animal condition (13%), euthanization method (9%), and other (capture method, number of complaints serviced, date of capture, and summary).

Fifteen states have altered or changed policies, laws, or regulations regarding the issue of nuisance wildlife control in the past two years. Of these states, 47% indicated the changes were more restrictive of NWCO activities, 27% were less restrictive of NWCO activities, 27% required euthanization of certain species, and 20% altered requirements for obtaining a NWCO license. These results indicate many state agencies are struggling with the issue of training, certification, and licensing as are NWCO.

These results show agencies support the principles and concepts promoted by Barnes (1997) but the political, social, and economic realities of managing these activities dictate this condition is not achievable at the present time. Furthermore, little change has occurred in how state agencies regulate NWCO during the past three years. While state agencies and NWCO support the concept of licensing, certification, and continuing education (Clark 1992; Barnes 1995a, b) there appear to numerous obstacles and challenges that must be overcome prior to implementing mandatory licensing, education, continuing education, and requiring financial responsibility. What are some of these obstacles that are preventing states from implementing the principles suggested by Barnes (1997)? A number of agencies responded with written comments that they currently do not have the resources (either financial or human) to implement a NWCO administrative oversight program. Other states indicated they no longer had statutory authority to regulate nuisance wildlife, except big game and migratory birds. Several states indicated they believed the regulatory oversight should be maintained by state regulatory or licensing agencies currently in place that regulate the structural pest control industry. A question that must be addressed if this option

Table 1. Perceived attitudes or beliefs and actual policies of state wildlife agencies with respect to administrative oversight of private nuisance wildlife control operators (N = 44) during 1997.

Concept	Perceived/Should Require (% positive response)	Actual Policy Required (% positive response)
Require License	90	56
Require Education Prior to Licensing	95	22
Require Continuing Education to Maintain License	68	4
Require Examination to Obtain License	95	15
Show Evidence of Financial Responsibility	60	5

is pursued is, "Who has legal authority with respect to resident wildlife?" State agencies must be willing to change policies to allow state agriculture departments the regulatory authority over resident species that cause problems. Are states willing to give up this regulatory control? Finally, several states indicated adoption of an oversight program would place a financial burden on small or part-time NWCO.

Some states view prerequisites or educational requirements as burdensome, time consuming, expensive, and exclusive (particularly for NWCO servicing rural areas). Several agencies believed this type of activity should be initiated by the NWCO themselves and one agency responded that ethics and morality cannot be legislated or regulated. Most states favor attacking this issue in the form of national guidelines that are general in nature and allow for variations due to local conditions (LaVine et al. 1996). LaVine et al. (1996) also reported that states believe the International Association of Fish and Wildlife Agencies, The Wildlife Society's Wildlife Damage Working Group, USDA-APHIS-Wildlife Services, or the National Animal Damage Control Association should take the lead in developing these guidelines.

Several state agencies were strongly opposed to providing any administrative oversight of NWCO. For instance, one state responded that nuisance wildlife control is "not a resource problem, per se, in that these species are abundant and are not in immediate need of protection." They went on to state that certification programs exist for wildlife biologists and foresters and that certification was not required to practice in either profession and the certification process was not administered by the state wildlife agency.

Seventy-eight percent of the states allow for the live-capture and release of nuisance wildlife. Most states allow nuisance wildlife to be released onto public land (71%) and private land (90%). Most states do require landowner permission (69%) prior to releasing nuisance wildlife onto private land. LaVine et al. (1996) reported 68% of states allowed relocation of nuisance wildlife. Comparing their data to this study would indicate there has been no increase in policies that restrict relocation of nuisance wildlife in the past several years. However, 17% of the survey respondents indicated they have implemented restrictions on what species may be translocated (primarily rabies vector species). This information suggests that state agencies are tightening policies regarding the translocation of nuisance wildlife. All of the states reported that disease concerns are the primary reason they do not allow translocation of nuisance wildlife. Other secondary reasons were the impact of nuisance wildlife on resident wildlife populations (45%), humane reasons (18%), and other (9%) which included issues related to public safety and a lack of suitable release sites. The results of this study also indicate the views of the state agency and NWCO are similar with respect to why animals should be euthanized (Barnes 1995a, b).

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DEFENSIBLE SPACE: A BEHAVIORAL APPROACH FOR MANAGING PREDATORS AT THE URBAN-WILDLAND INTERFACE

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ABSTRACT: Southern California has experienced rapid human population growth during the past 50 years. As housing continues to encroach into and abut previously undeveloped areas containing wildlife communities, conflicts between homeowners and predators have become common. Traditional methods of control (removal) of problem animals are often infeasible due to legislative constraints, local ordinances, public opinion, and environmental considerations. This necessitates developing alternative approaches to facilitate coexistence and diminish the opportunities for negative interactions. In the Defensible Space program, people are educated about local wildlife and provided animal behavior-based methods to respond to animal incursions. Though the system is not always 100% effective, it has diminished the overall number of complaints received and reduced most of the remaining complaints from panic-based to knowledge-based.

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INTRODUCTION

Since World War II, Southern California has rapidly increased both in human population size and the amount of urban/suburban development. Numerous studies have discussed patterns of population growth around pre-existing urban areas, and the ecological impacts to wildlife habitats and communities from urbanization and loss of open space (Sauavajot and Beuchner 1993; Scott 1995). Urbanization has also brought a change in demographics. A decreasing percentage of the population actively participates in consumptive recreation such as hunting or fishing, is part of a rural/agrarian society, or is aware of local wildlife populations (especially predators). One result of this demographic change is a growing number of people opposed to, or uncomfortable with, the killing of animals, unfamiliar with firearms, and unaware of safety concerns for themselves or their property when recreating in or living adjacent to open space lands. The purpose of this paper is to discuss a simple program developed over time to educate urban dwellers about local wildlife predators and assist them in dealing with predator interaction problems.

BACKGROUND

When the author first began his position as The Department of Fish & Game's (The Department) wildlife biologist for Santa Barbara and Ventura Counties in 1990, 10 to 20 calls per week were received from suburban dwellers either concerned about predator sightings or distressed by the suspected loss of a pet to a wild animal. In most cases, the offending predators were coyotes (*Canis latrans*), or bobcats (*Felis rufus*), and occasionally mountain lions (*Felis concolor*) or black bears (*Ursus americanus*). It is interesting to note, though many callers were aware of coyote presence, they were shocked to learn the remaining species live in open spaces adjacent to their homes. Most felt these were animals of the "wilderness area," and requested that they be relocated to some remote area. Roughly 75% of the callers favored non-lethal action or were adamant the offending animal not be harmed. The remaining 25% preferred immediate lethal justice, but refused to take action themselves or were prevented from doing so because of firearm use restrictions in urban areas. About 85% of the phone calls originated from Ventura County, especially the southern portion adjacent to Los Angeles County. As much of Santa Barbara County remains in agriculture, is developing at a slower rate, and has a contract with USDA Animal Services (formerly Animal Damage Control), wildlife-human interactions are not as prevalent. Until the 1960s the southeastern portion of Ventura County was mainly ranch lands supporting grain crops or grazing animals. Real estate developers recognized the value of these large tracts of ranch lands and acquired them as a cheap source of land on which to build homes for the expanding work force of the greater Los Angeles area (Bidwell 1989). Many of the cities in this area function as bedroom communities with residents commuting long distances daily. This lifestyle serves to further isolate them from the surrounding natural landscape and its wildlife inhabitants. In order to assist individuals in this area, a large scale education program had to be developed and made available to them in a format both easy to understand and apply. Through a series of accidental observations and occurrences, the concept of "Defensible Space" was born.

THE PROGRAM

"Defensible Space" is a catchy phrase for a simple program founded on common sense and basic wildlife biology principles. The phrase is borrowed from the California Department of Forestry's fire protection plan for homeowners along the wildland interface. There are not any common guidelines between the two, but rather just the common premise of taking responsibility for the safety of your own backyard. There are three steps in the program, each building on the previous one.

Step One: Know Your Wildlife Neighbors

When contacted about their "nuisance wildlife" problem, most individuals cannot identify the offending animal, let alone know anything about an individual species' food, social or habitat requirements. By providing informational leaflets to homeowners with species identification information, general habits, and other helpful hints, this gap can be bridged. Before mailing the written material, often up to 20 minutes are spent on the phone going over the information in detail and providing human-related analogies to help non-biologists understand biological concepts. If the individual is part of a homeowners' association, a meeting of the group is suggested where animal slides, skins, and skulls can be shown to further provide detailed information on local wildlife. Often an individual's great amount of concern or fear is due to a lack of knowledge. Although time consuming initially, increasing the knowledge base has a direct correlation to decreasing the amount of panic and demands for relocation or extirpation. The first is usually not an option because of ecological concerns, and in Southern California, the second is not an option because of public/political opinion concerns. With education, though, many people come to understand that, on occasion, some animals may have to be "removed." The basic wildlife knowledge background also prepares the human part of the equation for step two which involves recognizing and eliminating attractions.

Step Two: Eliminate Attractions

Predators are incredibly opportunistic and intelligent creatures. Species survival is based on reproductive success, and reproductive success is based on maintaining a positive energy balance. The easiest way to keep a positive energy balance is through an ample and easily caught food supply. What better source is there than domestic pets left unguarded and outside during the night-time hours? Or an unfenced vegetable garden where rabbits and squirrels grow fat, providing food for carnivores? Many urban interface dwellers will actively feed wildlife; purposefully leaving out bowls of pet food or scraps. Every spring, many posted signs show up in the neighborhoods, "Lost Cat," "Lost, Small Dog." These animals are not the victims of some underground pet-napping ring, but rather of opportunistic wildlife. Homeowners must recognize that if they want to avoid negative interactions, they must be responsible and make sure their immediate backyards are free of attractions. Step two involves not only pointing out the obvious attractions which should be removed (unattended pets, garbage, pet food, pooled water, improperly housed chickens, ducks, etc.), but also having the caller describe their yard to determine how proper fencing, vegetation trimming or landscaping changes might decrease the chance of negative interactions. Step two is often the most difficult of the three steps in which to achieve success since humans are probably the most difficult species of which to modify behavior. This fact, plus the perceived need of many people to take some kind of action, led to the development of step three.

Step Three: Active Coexistence

A hundred years ago, wilderness travelers carried firearms, knives, and other weaponry to protect themselves. People were wary of, and respected mother nature. Predators were hunted aggressively, often with dogs, and avoided people. Today, isolation from the natural world has changed people's views of predator species. Instead of eliciting an immediate fear response, or at least recognition of their potential threat, today they are often viewed as warm, fuzzy creatures. Recreationists, especially in urban open spaces, carry only a camera to shoot with. If people happen to see a predator, they will often stare at it, ooh and ah, and remain as passive as possible so as not to frighten the animal. People are becoming less of a threat, yet most do not realize how their attitude change toward wildlife might be exacerbating their "nuisance wildlife" problems. In response to various individuals who felt they had to do something more active to discourage these predators from taking up residence in their backyards, yet did not want to harm them, the author began to look at several ways the animals' behavior might be slightly modified. The goal was to increase the animals' human wariness level. Animals maintain territories with inter- and intra-specific aggression. It can be mild, violent, or sometimes lethal. Discharging firearms is the traditional method for human-inflected aggression toward wildlife and has been shown to be effective, even when not fired directly at the animal. Most urban areas, though, have firearms closures for safety reasons. It is reasonable to assume projectiles of any kind might function equally well in controlling nuisance wildlife. One of the most successful has been the common garden hose. Teamed with a high pressure spray head, garden hoses have been shown to repel bobcats, coyotes, and even mountain lions. One homeowner, with her own fire hydrant and stand pipe, turned the fire hose on a mountain lion who had taken to crossing her driveway at midday. The lion opted to not return during daylight hours again. People are encouraged to outfit their garden hose with a high power head and washers so the hose can be left on at all times. It becomes a quick tool for increasing the human wariness level. Other water-based projectiles such as a water balloon launched with a slingshot, and "supersoaker" squirt guns, both loaded with a mild water/ammonia mixture (10:1) have proved effective against coyotes and bobcats. Pellet guns and wrist rockets work in less urban areas. Aggressive and savvy dogs can be an amazing tool. Personal observation of a militant Walker hound has shown how even a well established pack of coyotes will circumvent this dog's turf in order to avoid interaction.

All of these tools or actions come with the caveat that the aggressive action is intended to be mild, and the predator should never be cornered or put in a defensive position. In addition, it is stressed that these actions will not deter the animal from using the areas during the hours between dusk and dawn when most predator activity occurs. Thus, it is especially important to follow step two and remove attractions. Wildlife has a need to utilize these habitats. What this technique is intended to do is adjust their behavior so they are not using people's immediate backyards during the majority of the daylight hours. Most people never utilize step three, but they feel better knowing they can do something if they wish to.

CONCLUSION

People need to understand "coexistence" is an active term; it requires some sort of action even if it is just increasing one's knowledge as in step one. Though the "Defensible Space" concept is not always 100% effective, it has, over the past eight years, decreased the number of panic stricken and uninformed phone calls received. During the late spring when most calls come in, the author may only get 10 to 20 calls per month. Very few people request relocation anymore, and many just want to record a sighting. Other agencies that might field calls report similar results. Whenever there is a widely publicized incident anywhere in the state, especially with a mountain lion, calls momentarily increase.

One of the most important aspects of the program is increasing knowledge and making sure this specific type of impact to wildlife is addressed through environmental review processes. When new housing developments are planned, and with them open space requirements, human/wildlife interactions should be addressed under impacts to wildlife and be provided as a disclosure to prospective buyers or tenants. The information in steps one and two should be provided to new residents. Making new residents aware of the wildlife and wildlife habitat in their area can reduce the number of requests for wildlife removal. This increased awareness will ultimately benefit all wildlife.

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ECOLOGY AND MANAGEMENT OF COYOTES IN TUCSON, ARIZONA

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ABSTRACT: Increasingly, coyotes are becoming common residents of urban areas in the western United States, including Tucson, Arizona. The authors' objectives were to determine the home-range size of coyotes in Tucson, the habitat encompassed by the home ranges of these coyotes compared with the habitat available in Tucson, and the use of habitats within the home range, compared to their availability in the home range. To address these objectives, the authors trapped, radiocollared, and followed 13 coyotes via radiotelemetry in Tucson, Arizona. Seven coyotes were in less-densely populated areas (< 1 house/0.4 ha, called rural) of Tucson; six coyotes were in densely populated areas (> 1 house/0.4 ha, called urban) of Tucson. The authors used RANGES V to determine home-range size and the geographic information system ARC/INFO to analyze habitat use. The home-range size of Tucson coyotes varied from 129 to 3,279 ha (95% MCP). Coyote home ranges in rural areas included a greater proportion of natural habitat and a smaller proportion of residential habitat than was available in the study area. Coyote home ranges in urban areas included a greater proportion of vacant areas and a smaller proportion of natural areas and parks than was available in the study area. Within the home range, coyotes in rural areas preferred (used greater than available) parks and washes, and avoided (used less than available) all other habitats. Within the home range, coyotes in urban areas preferred residential habitat; they avoided commercial areas and vacant areas. Coyotes may have been preferring areas where food and cover was most abundant.

KEY WORDS: *Canis latrans*, coyotes, habitat use, urbanization

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INTRODUCTION

Since the 1980s, urbanization has added new dimension to the study of coyote ecology. Coyotes persist in urban habitats (Howell 1982; Quinn 1991), and this adaptability makes them ideal animals with which to study the affects of urbanization on wildlife (Bekoff and Wells 1986), as well as the effects of wildlife on urban areas. To date, however, no studies have investigated the way in which coyotes use urban areas. Some studies have investigated coyotes on the outskirts of urban areas (Shargo 1988; Bounds 1993), but have not concentrated on their presence in urban centers. Researchers recorded the presence of coyotes in Los Angeles, California (Gill and Bonnett 1973; Howell 1982) and in Seattle, Washington (Quinn 1991), but did not quantify or explain their findings.

The authors' objectives were to determine home-range size, evaluate the habitat encompassed by the home range compared to habitat availability in Tucson, and quantify habitat use compared to its availability within the home range. Three questions relative to this objective were asked: What is it home-range size of Tucson coyotes and how does it compare to the home-range size of coyotes obtained by other researchers in rural settings? Do home ranges encompass certain habitats out of proportion to their availability in Tucson? And finally, are certain areas within the home range used more than others?

STUDY AREA

The area in which the coyotes were captured and collared encompassed most of the city of Tucson, Arizona, and a few urbanized areas directly outside of the city limits. Tucson, which is in eastern Pima County, currently encompasses 493 km^2 with an estimated population of 456,100 (Tucson Planning Department 1996). Tucson is situated in the Sonoran Desert, the most varied and the hottest of the North American deserts. The elevation is 745 m in midtown Tucson, and increases toward the foothills of the Santa Catalina Mountains to the north, the Tucson Mountains to the west, and the Rincon Mountains to the east. The climate in Tucson is characterized by low, unevenly distributed rainfall (about 28 cm annually; Sellers and Hill 1974), low humidity, high air temperatures and periodic strong winds (Hastings and Turner 1965).

Determination of Study Areas within Tucson

Although the authors concentrated their trapping efforts on urban areas of Tucson, some coyotes were trapped in less-densely populated areas than others. In addition, some coyotes ranged from the areas in which they were trapped to less-densely populated areas. To deal with the variability in habitats used by coyotes, the collared animals were divided into two groups, each with its own study area. Six coyotes were located in less-densely populated areas of Tucson (< 1 house/0.4 ha, called rural); seven coyotes were located in more-densely populated areas of Tucson (> 1 house/0.4 ha, called urban).

Determination of Land-use Categories in Study Areas

The WHIPS database (Shaw et al. 1996) was used as a basis for creating habitat categories in the study area. The WHIPS database assigned all of eastern Pima County, including Tucson, to one of 33 land-use categories at a resolution of 0.4 ha. The authors collapsed across WHIPS land-use categories to create seven habitat categories. The new habitat categories were formed based on information from Shaw et al. (1996) on the amount of native and non-native vegetation present, the amount of human activity present, and on obvious structural differences and similarities among WHIPS land-use categories.

Natural habitat included residential areas with low-density housing (<1 house/0.4 ha), state and federal parks, privately-owned natural open space, and cropland. Commercial habitat included industrial areas, malls and other shopping centers, public buildings, and office buildings. Park habitat included schools, military grounds, cemeteries, zoos, golf courses, neighborhood, district and regional parks, and stables or pens with horses or cows. Vacant habitat included mines, landfills, graded vacant land, abandoned agricultural lands, and railway yards. Residential habitat included neighborhoods with >1 house/0.4 ha. Wash habitat included major and minor rivers and washes. Road habitat included only roads with ≥4 lanes; smaller roads were incorporated into the surrounding habitat categories.

Vegetative Characteristics of Habitat Categories

To construct the land-use categories for their database of eastern Pima County, Shaw et al. (1996) sampled vegetation from their land-use categories. They found that golf courses and neighborhood parks (the authors' parks habitat) had the highest total vegetative cover (Table 1). Areas equivalent to the natural habitat had the highest percentage of native plants, and the most vegetation that was dense enough to serve as escape cover. Structural diversity of vegetation was higher in human-designed urban landscapes such as medium-density residential areas (1 to 3 houses/2.5 ha), zoos, schools, and cemeteries (the authors' residential and park habitat) than in areas with native vegetation. Based on these vegetative characteristics, Shaw et al. (1996) ranked natural open spaces, federal/state parks, and low-density housing (the authors' natural habitat) as the most valuable wildlife habitat in Tucson. The next highest-ranked group of land use categories included medium density housing, schools, parks, golf courses, and cemeteries (the authors' residential and park habitat). The least valuable land use categories for wildlife included landfills, abandoned agricultural lands, and railways (the authors' vacant habitat).

METHODS

Trapping and Radiocollaring

The help of a professional trapper was enlisted to live-trap coyotes using padded leg-hold traps (#3 Victor Softcatch Coilspring). Fourteen coyotes were trapped and radiocollared from October 1996 through March 1997, and five coyotes from December 1997 through January 1998. The data from 13 of these coyotes is presented here. The authors tried to trap in locations that represented a variety of areas and human population densities within Tucson. They were not able to trap everywhere they chose, however, because some landowners would not allow them to trap on their property; other areas were too often traversed by dogs and people that might step in a trap. The traps were closed at dawn and opened at dusk daily to minimize the time that a coyote spent in a trap, and to minimize the chances of trapping non-target animals. Each trapped coyote was immobilized with a noose rod, muzzle, and nylon stockings to tie its legs (Woolsey 1985). The coyote was then fit with a radiocollar (Telonics Inc., Mesa, Arizona). Each trapped coyote was weighed, its sex and reproductive condition determined, and its age approximated (<12 months, >12 months, >24 months) by looking at tooth wear (Gier 1968) and, for young of the year, by looking at the condition of the coat and tail. Finally, the animal's general health was evaluated by checking for external parasites, wounds, or other obvious signs of ill heath. The coyote was then released at the trapping site.

Radiotelemetry

The authors worked with technicians to locate coyotes by homing with hand-held Yagi antennas (White and Garrott 1990). They attempted to visually locate animals, if possible, without trespassing or disturbing the animal. Each technician's error was tested in locating coyotes by placing radiocollars at locations, known to the tester, in various habitats and having technicians estimate collar locations via their usual homing procedure (e.g., Litvaitis and Shaw 1980; Bounds 1993).

Table 1. Characteristics and ranking (based on vegetative characteristics) of wildlife habitats in Tucson, Arizona (Shaw et al. 1996).

Habitat Category	Vegetative Characteristics	Ranking
Natural	Most native vegetation; Most escape cover	Most valuable
Residential	High structural diversity	Intermediate Value
Parks	High structural diversity; Most vegetation overall	Intermediate Value
Vacant	None of the above	Low Value

Data was collected throughout the year. Each coyote was located ≥2 times/week, once during the day and once at night. Day and night were divided into two, six-hour blocks, and an equal number of locations during each block were made. Coyote locations were recorded on enlarged sections of a Tucson street map. The locations were then entered into Arc/View (desktop mapping system, ESRI, Redlands, California) as a coverage that overlaid the WHIPS database (Shaw et al. 1996). Finally, the coyote locations were converted into ARC/INFO (geographic information system, ESRI, Redlands, California) coverages to assign the locations UTM coordinates.

Home-range Size Estimation

The ARC/INFO coverages of coyote locations were imported to the home-range package RANGES V to estimate home-range size. Two methods of home-range estimation were used: 1) the minimum convex polygon (MCP) method (Mohr 1947); and 2) the adaptive kernel method (Worton 1989). For both methods 95% of all points to estimate home-range size were used. The MCP method is commonly used in coyote research (e.g., Litvaitis and Shaw 1980; Althoff and Gipson 1981; Andelt 1985; Bekoff and Wells 1986; Bounds 1993); this method was used to compare the data with that of other studies. The adaptive kernel method is a nonparametric method of estimating home-range size that allows one to determine core areas of activity, an important factor in urban areas where coyotes habitat may be fragmented. The adaptive kernel home-range estimations was used in the analyses of habitat use.

Determination of Use Versus Availability of Habitats

Home range versus study area. The habitats that were encompassed by each home range were determined by importing the 95% adaptive kernel home ranges from RANGES V to ARC/INFO as polygons that were the shape and size of each home range. These polygons were used to clip out the habitat categories in each home range, and then the amount of each habitat category that was within the home range was determined. The amount of each habitat category that was in the study area (either rural or urban) was also determined. The proportion of each habitat category that was within the home range was compared with the proportion of each habitat category that was in the study area by using Chi-square tests of homogeneity (Daniel 1991) on all home ranges and on individual home ranges. It was determined which habitat categories were encompassed by home ranges more or less than they were available in the study area by constructing simultaneous 95% confidence intervals with Bonferroni corrections on the proportions (Manly et al. 1993).

Locations within the home range versus the home range. It was determined if certain habitats within the home range were being used out of proportion to their availability in the home range by comparing the number of coyote locations in each habitat category within the home range with the number of locations that would be expected in each habitat category within the home range if the habitat categories were being used in proportion to their availability. The number of locations that were in each habitat category was determined by intersecting the coverage with the coyote locations with that of the coyote's home range polygon. The previously determined proportion of each habitat category in each home range was used to determine the number of expected coyote locations in each category. Chi-square tests of homogeneity (Daniel 1991) were used on all home ranges and on individual home ranges to compare the actual number of locations in each habitat category with the expected number, if use equaled availability within the home range. Which habitat categories were used more or less than they were available in the home range was determined by constructing simultaneous 95% confidence intervals with Bonferroni corrections on the proportions (Manly et al. 1993).

RESULTS

Home-range Size Estimates

Preliminary estimates of technician error ranged from 0 to 100 m. The MCP (95%) home-range estimates of coyotes ranged from 129 ha to 3,279 ha in size. The home-range size of rural coyotes ranged from 312 to 3,279 ha, and the home-range size of urban coyotes ranged from 129 to 1,637 ha. Although rural coyote home ranges were larger than those of urban coyotes, both groups of coyotes contained three individuals with home ranges under 500 ha.

Habitat Encompassed by Home Range versus Study Area

Within each study area, the pooled home ranges of coyotes encompassed habitat categories out of proportion to the availability of the habitat categories ($P < 0.0001$). Each individual home range also encompassed habitat categories out of proportion to their availability in the study area ($P < 0.0001$). Overall, coyotes home ranges in rural areas contained a greater proportion of natural areas than available, and a smaller proportion of residential areas than available; all other habitat categories were used in proportion to their availability. Overall, coyote home ranges in urban areas contained a greater proportion of vacant areas and roads than available, and a smaller proportion of natural areas and parks than available. All other habitat categories were used in proportion to their availability. Individual coyotes, however, showed a great deal of variation in their preferences for various habitat categories (Figure 1 and Figure 2).

Habitat Use within the Home Range

Coyotes in both study areas used habitat categories within the home range out of proportion to their availability ($P < 0.0001$). Overall, coyotes in rural areas preferred (used greater than available) the park and water habitat categories; they avoided (used less than available) all other habitat categories. Overall, coyotes in urban areas preferred residential areas. They avoided commercial areas, vacant areas, and roads, and used natural areas, parks, and water in proportion to their availability. Once again, however, there was much individual variation in the use of various habitat categories by individual coyotes (Figure 3).

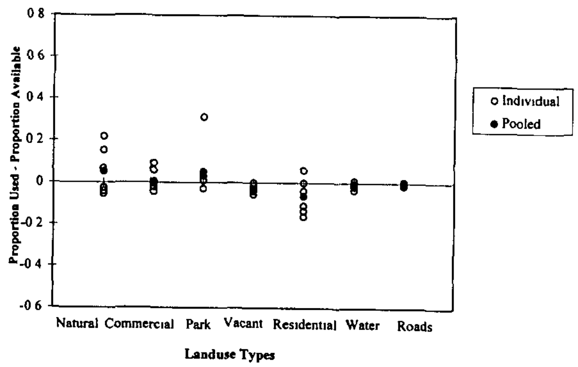

Figure 1. Habitat in home ranges of coyotes versus rural study area. The proportion of each home range containing each habitat category is subtracted from the proportion of that habitat in the study area to illustrate the variation in use of habitats by individual coyotes. The pooled value for each habitat is also shown.

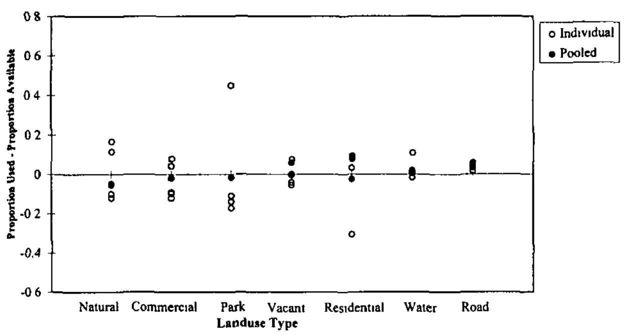

Figure 2. Habitat in home ranges of coyotes versus urban study area. The proportion of each home range containing each category is subtracted from the proportion of that habitat in the study area to illustrate the variation in use of habitats by individual coyotes. The pooled value for each habitat is also shown.

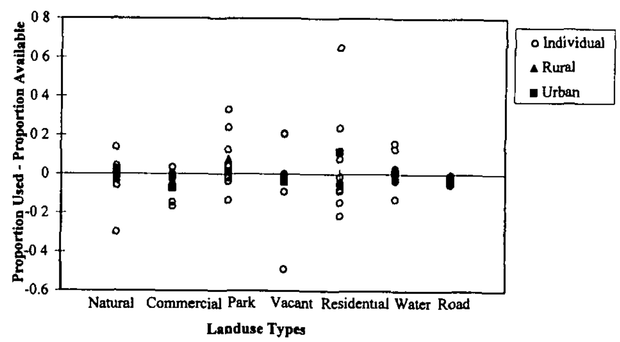

Figure 3. Habitat use versus availability within home ranges. The proportion of locations within each habitat in the home range is compared to the proportion of that habitat that is available within the home range to show the variation in use by individual coyotes. The pooled value for rural and for urban coyotes is also shown.

DISCUSSION

Home-range Size Estimates

Many radiotelemetry studies have documented home-range sizes for coyotes in relatively undisturbed areas (Messier and Barrett 1982; Woodruff and Keller 1982; Andelt 1985; Windberg and Knowlton 1988; Mills and Knowlton 1991) and in areas where agriculture or ranching have modified the landscape (Danner 1976; Andelt and Gipson 1979; Fisher 1980; Althoff and Gipson 1981). These areas are less densely inhabited by humans than are urban areas but vary, nonetheless, in regard to their exploitation by man. This variation has been apparent in the wide range of home-range sizes recorded for coyotes. Home-range size of resident coyotes, using the 95% MCP method has been found to vary from around 200 ha (Andelt 1985; Windberg and Knowlton 1988) up to 1,700 to 2,400 ha (Bekoff and Wells 1981). The 95% MCP home ranges for both groups of coyotes are similar to those reported by other studies, although there were coyotes with home ranges that were both larger and smaller than the values found by other researchers. Thus, it is not obvious that living in an urban environment affects the size of an area that a coyote uses during daily activities.

Habitat in the Home Range Versus the Study Area

At the level of the home range, coyotes in rural Tucson preferred the natural habitat category which, because of its vegetation characteristics, was ranked highly as wildlife habitat by Shaw et al. (1996) (Table 1). Thus, coyotes living on the outskirts of Tucson seem to be able to survive by simply avoiding encroaching urbanization. At the level of the home range, coyotes in urban Tucson preferred vacant areas, which Shaw et al. (1996) deemed the least valuable wildlife habitat, and avoided natural areas and parks, which Shaw et al. (1996) ranked higher than vacant areas in their value to wildlife. Although surveys of the vegetation and prey base in vacant areas have not been conducted, two of the collared coyotes were trapped in a landfill, and radiotelemetry observations confirmed that some coyotes do hunt in landfills and vacant agricultural land. Other coyotes have been observed, however, spending most of their time in parks, golf courses, and cemeteries. Although the pooled data from all coyotes do not indicate a preference for parks and residential areas, some individuals undoubtedly prefer these areas.

Habitat Use within the Home Range

The observed preference by coyotes in rural areas for park habitats may, in part, be a result of the fact that four rural coyotes were trapped in a golf course. All of these coyotes were found in the golf course a large proportion of the time soon after they were collared. Only one of these coyotes still resides exclusively in the golf course, however, two of the other three coyotes have not been observed in the golf course in >6 months. Although the home-range estimates for these animals still reflect their earlier use of the golf course, the later locations are concentrated in natural areas. For this analysis, all locations were lumped together to obtain home-range estimates. Later, it is planned to have enough locations for each coyote in different seasons to block the locations by season; this method will allow the authors to observe and quantify shifts in home range size and habitat use within the home range with time. In preferring parks, coyotes in rural areas are showing a preference for what Shaw et al. (1996) considered a valuable wildlife habitat, however.

The preference for residential habitats by coyotes in urban areas coincides with the classification by Shaw et al. (1996) of these areas as good wildlife habitat (Table 1). Natural areas and parks were used in proportion to availability by coyotes in urban areas; both were highly ranked by Shaw et al. (1996). The vegetation in park and residential habitat categories is more structurally diverse than that in natural areas. Other studies have found that coyotes preferred the more structurally diverse forested areas over open areas, and attributed this preference to the availability of prey and cover (Litvaitis and Shaw 1980; Roy and Dorrance 1985). In preferring residential areas, coyotes in Tucson may be showing a preference for structural diversity of vegetation, and possibly a greater prey abundance and availability of cover. Although coyotes may be preferring these aspects in certain habitats, the availability of food, water, or cover was not quantified.

MANAGEMENT IMPLICATIONS

This and other studies (Litvaitis and Shaw 1980; Andelt 1985) indicate that coyotes display a wide variety in home-range size (Andelt 1985; Roy and Dorrance 1985) and in habitat use (Litvaitis and Shaw 1980; Roy and Dorrance 1985). Wildlife managers in Tucson would like to know enough about what influences habitat preference in urban areas to be able to help residents encourage or discourage the presence of coyotes in their neighborhoods. To do this, other questions need to be answered to more fully understand how coyotes are using Tucson. Information is currently being gathered on the health of Tucson coyotes, their activity patterns, and their social structure to better address these issues.

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MANAGEMENT OF CONFLICTS BETWEEN URBAN COYOTES AND HUMANS IN SOUTHERN CALIFORNIA

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ABSTRACT: An apparent increase in coyote-human conflicts, notably attacks on humans, demonstrates that such incidents are not rare in California. The authors discuss coyote attacks on 53 humans, resulting in 21 instances of human injury, over the last decade. These illustrate repeated, predictable pre-attack coyote behavior patterns. Specific changes in human environments and in human behavior that have contributed to coyote attacks are discussed. Case histories of attacks reveal contributing factors and suggest appropriate corrective and preventive actions. Padded leghold traps have been the most effective and efficient tool in removing problem coyotes and changing the behavior of coyotes to fear humans and the urban environment. Long-term solutions will require changes in human behavior. Humans must come to view large mammalian predators as a potential hazard. Increased public education is needed to improve methods of landscape management, refuse disposal, care of pets, and recognition of the need for predator management.

KEY WORDS: coyote, urban coyote, coyote-human attacks, coyote behavior, human safety

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INTRODUCTION

Prior to 1981, coyote (*Canis latrans*) attacks on humans were thought to be rare, although coyotes frequently interact with humans throughout much of North America (Carbyn 1989; Young and Jackson 1951). Howell (1982) reported the tragic death in 1981 of a 3-year-old girl in Glendale, California resulting from a coyote attack. He also documented eight other cases in Los Angeles County, over a seven-year period (1975 to 1981), of people being attacked. Carbyn (1989) summarized information from warden and park ranger reports from Banff and Jasper National Parks, Canada, and Yellowstone National Park, Wyoming, which involved 20 coyote attacks on humans over a 28-year period (1960 to 1988). Fourteen of the attacks resulted in injuries; four cases involved serious injuries to small children.

Connolly (1992) noted that 56 coyote-related human health and safety incidents nationally were reported to USDA-APHIS-Animal Damage Control offices during fiscal year 1990. These were in addition to reports of coyote predation on pets, as well as on livestock and poultry. He noted that coyote attacks on humans are "an unusual but significant aspect of coyote management in modern society." The diversity of damage situations noted in Connolly's paper reflects the coyote's adaptive abilities as related to modern human society.

The number of coyote attacks on pets reported annually to USDA Animal Damage Control (ADC, now "Wildlife Services") in California has risen steadily, from 36 incidents in 1991 to 394 in 1996 (John E. Steuber, pers. comm.). Many other cases were reported to veterinarians and animal regulation organizations in counties not served by ADC. Attacks on pets, especially as they relate to human safety and coyote behavior will be discussed. In many instances, they may be a predictive precursor to more serious coyote-human conflicts.

Coyote attacks on humans are no longer rare or unusual in many California urban fringe areas. Developed sites such as parks, residences, commercial centers, and trails used for recreation and exercise, in or near wildland areas, are all susceptible to coyote-human conflicts. Over the last decade there has been an alarming increase in the number of reported coyote attacks on children, adults, and pets in California. Howell (pers. comm. 1982), Walter E. Howard (pers. comm. 1981 and 1998), and Carbyn (1989) believe that, in these instances, coyotes have lost their fear of humans and have regarded the children as prey.

In this paper, coyote attacks on 53 people in 16 locations, resulting in 21 bites, is documented and described. In addition to those bitten, coyotes harassed more than 32 individuals over a 10-year period. Case studies of the verified coyote attacks on humans, discussed in the text below and summarized in Table 1, provide details surrounding the circumstances of each incident. The authors review changes in the environment, social values, and human behavior in California that have contributed to this problem. They describe the methods utilized in solving these conflicts, and provide recommendations on ways to prevent future coyote attacks on humans.

While none of the coyotes involved with these human bite cases was found to have rabies, this disease is endemic to much of the U.S., including California, and it has been found in coyotes. If rabies were to become prevalent in coyotes in the urban interface, it could have severe public health and safety consequences because of the high risk of contact between coyotes and people or their pets.

Table 1. Verified Coyote Attacks, August 1988 to September 1997.

Location	Date	Victim	Attack Details
Oceanside	08/88	8-year-old Girl	Approached by coyote while rollerskating, after she had fallen. Coyote tugged at her skate and was scared off by two women who threw rocks. (Morning)
Oceanside	08/88	4-year-old Boy	Nipped and bruised by coyote, while playing in yard. (Morning)
Oceanside	08/88	3-year-old Girl	Coyote grabbed child by the leg and pulled her down, then bit her on head and neck. Coyote chased off by mother and neighbors. (Early evening, 7 p.m.)
San Diego	10/88	Adult Female	Bitten by coyote in backyard, while talking on phone. (Daytime)
Madera County (Reds Meadow)	06/90	5-year-old Girl	Attacked and bitten in head while in sleeping bag at campground. (Night, 3 a.m.)
Madera County (Reds Meadow)	06/90	2 Persons	One person bitten on foot through sleeping bag; one bitten on hand. At same campground as above.
Laguna Niguel	09/91	Adult Male	Man chased, and his poodle was ripped from his arms; the dog was taken by the coyote.
San Clemente	05/92	5-year-old Girl	The girl was attacked, and climbed a swing set to get away; she was bitten several times on her back. Mother chased off the coyote. (Daytime)
Newport Beach	07/94	2-year-old Boy	Coyote stalking boy. Child did not move before mother rescued child, when the coyote was five feet away, crouched for attack. Coyote remained while mother shouted and backed into home. Coyote eventually left. (Daytime)
Griffith Park	10/94	Adult Male	Man with no shirt or shoes bit by coyote. (5 p.m.)
Griffith Park	03/95	Adult Male	Man with no shirt bit by coyote. (12 noon)
Griffith Park	03/95	5-year-old Girl	Coyote stalked and then knocked down child twice, as reported by witness. Mother rescued child and left. (Daytime)
Griffith Park	06/95	Adult Female	Woman in shorts, no shoes, preparing food, bit by coyote. (Daytime)
Griffith Park	07/95	Adult Male	Man bitten by coyote while sleeping on lawn. (Daytime, 2:45 p.m.)
Griffith Park	07/95	Adult Male	Man bitten by coyote while sleeping on lawn. (Daytime, 4 p.m.)
Griffith Park	07/95	15-month-old Girl	Coyote was chased away once, then returned to attack infant in jumpsuit; child suffered bites to leg. (Daytime, 4 p.m.)
Laguna Nigel	06/95	6 Adults and Children	All were chased from patio table by coyote. Chicken dinners taken and eaten, despite yells of adults in an attempt to scare the coyote.
Laguna Nigel	06/95	Adult Male	Man attacked while lying on chaise lounge, stargazing. Bitten on bare foot. (Night)
Laguna Nigel	06/95	Adult Male	Bitten on bare foot while getting paper from front yard. (Mid-morning)

Table 1. Continued

Location	Date	Victim	Attack Details
U.C. Riverside	06/95	7-year-old Boy	Victim bitten as three boys were chased. (Late afternoon)
U.C. Riverside	06/95-11/95	Several Adults	Joggers were chased. (Late afternoon)
U.C. Riverside	11/95	3-year-old Boy	Children chased while playing, and one bitten. (Late afternoon)
San Juan Capistrano	01/97	2 Adult Females	Attacked and one woman bitten twice on left ankle and pulled to ground. Both yelled, used alarm device, and swung handbag. Had no food.
San Juan Capistrano	01/97	Adult Female	Coyote assaulted employee, grabbed lunch pail, and ran.
San Juan Capistrano	01/97	Adult Female	Coyote charged employee, took purse containing lunch and personal belongings.
San Juan Capistrano	01/97	Adult Female	Coyote stalked employee but was frightened off by other workers.
San Juan Capistrano	01/97	3 Adult Females	Aggressive coyote charged 3 employees; was frightened off by van driver honking horn.
San Juan Capistrano	01/97	Adult Female	Coyote charged employee, attacked, and took purse.
San Juan Capistrano	01/97	Adult Male	Coyote attacked man, bit shoe, no injury. Coyote refused to retreat. (Before daylight)
San Juan Capistrano	01/97	Adult Male	Coyote jumped on back of employee, biting his backpack. Was knocked off and retreated.
South Lake Tahoe	02/97	Adult Male	Man attacked and bitten on hand while feeding coyote. (Late morning)
South Lake Tahoe	02/97	4-year-old Girl	Child in yard attacked from rear and severely injured on face. Heavy snowsuit protected all but face. Father rescued child. Coyote stayed in unfenced yard and was shot by police. (Late morning)
San Clemente	03/97	2-year-old Girl	Child was stalked, but was saved by father when coyote was in freeze mode, 4 feet away, prior to attack. Father needed help of second man, as yelling had not deterred coyote. Coyote slowly left area with much hesitation after being hit with stick. (Late morning) Coyote returned on several days after until trapped.
Pomona	09/97	Adult Male	Man was stalked, then attacked by two coyotes, and bitten on ankle. (Early evening, in daylight)

COYOTE-HUMAN CONFLICTS 1988 TO 1997: CASE HISTORIES

Most of the coyote cases occurring between 1991 and 1997 are ones in which the senior author (R. O. Baker) was personally involved as a consulting wildlife biologist for Animal Pest Management Services (APM) of Chino, California. Other cases were brought to the authors' attention by news articles, calls from California Department of Fish and Game, information reported to the USDA-APHIS-ADC (WS) program, or calls received at California State Polytechnic University-Pomona (Cal Poly). The senior author is a professor and researcher on wildlife, public health, and integrated pest management issues at this University, and his visibility draws many public information inquires. Additional cases have been brought to light by a survey initiated by the senior author through the Wildlife and Vertebrate Conflicts Project at Cal Poly-Pomona. The junior author (R. M. Timm) researched circumstances surrounding the bite incidents that occurred in 1988 and 1990. The cases reviewed here are from southern California, except for two from South Lake Tahoe that seem to have the same type of causal relationships.

From the authors' perspective, coyote activity complaints escalated in the summer of 1991, with the senior author receiving more than a dozen calls from citizens in Anaheim Hills, Orange, Laguna Niguel, San Clemente, and San Juan Capistrano. The complaints involved three cases of horseback riders whose horses were being chased or nipped in the Orange area of the Santa Ana River trails system. Two dogs were attacked while on a leash in the same Santa Ana River area; one of the two dogs was killed, the other injured, and the adult owners were traumatized but not bitten. One dog owner in Anaheim Hills saved a poodle from being taken over her yard's rear wall. The dog had been let out of the house for a comfort break; it was grabbed, by a coyote, from the patio next to a sliding glass door where adults were sitting inside. The coyote returned daily about the same time until it was trapped. Most of the other calls involved coyotes in parks, in front and rear yards of residences where children played, or were calls from owners who had lost pets to coyotes. All totaled, seven adults reported being approached or harassed by coyotes.

All coyote-human conflict cases in progress that came to the attention of the senior author were first evaluated by phone to determine the severity of the problems. It was the desire of the authors to find out what the callers had done themselves or could do to resolve the problem. Many people who lost pets were advised on what they could do to prevent future problems, and they were often referred to kennel or fence companies, and to a local animal regulation agency. Before any population dispersal or reduction program was initiated, a thorough site evaluation was performed. This evaluation involved looking for signs of all animal species in the area, and for human activity that might affect the project. Further, human attitudes of the client and the community were examined, and the need for public education was evaluated. Alternative measures, rather than coyote population reduction, were usually initiated unless a human had been attacked. In instances of attacks on humans, some type of population reduction and/or behavioral modification was promptly implemented.

These cases demonstrate the manner in which human-caused changes in the environment, coupled with changes in human behavior toward coyotes, may result in the development of serious human-coyote conflicts. Public awareness of the danger of coyotes and other large predators to humans and pets was found to remain a limited and localized issue, primarily existing where prior problems had occurred. The general public's lack of concern and awareness is a serious problem and is the real root of coyote-human conflicts.

Information on human attacks by coyotes from August 1988 to September 1997 that have been personally verified by the authors are listed in Table 1. These cases are discussed roughly in chronological order of their occurrence. Observations of common pre-attack coyote behavior that may be predictive of subsequent attacks on humans are included. The methods used to successfully resolve the problems are described.

<u>Oceanside, San Diego County, 1988</u>

Three children were approached or bitten in separate events on August 16, 17, and 18, 1988 in the Oceano, Hermosa, and Peacock Hills area of Oceanside. In the three weeks prior to these events, USDA-ADC personnel had received 30 to 40 complaints of coyotes attacking or killing household pets, or approaching people during daylight hours in the Oceanside area. During approximately the same time period, the commanding Brigadier General of the adjacent Camp Pendleton Marine Base had reported that coyotes harassed his wife and threatened the family's dog.

In one incident, when an 8-year-old girl fell while roller-skating, a coyote ran at her and grabbed her skate. Two women chased the animal away by throwing rocks at it. In a second incident, a 4-year-old boy playing in front of his grandfather's home was nipped in the knee by a coyote, causing a bruise. In a third incident, 3-year-old Jessica Lee, while playing in her grandfather's driveway, was grabbed on the leg by a coyote that pulled her down, biting her on the leg, neck, and head. Her mother and neighbors screamed at the coyote and chased it away. During the week following the three incidents involving children, an ADC Specialist removed three coyotes from the area, two by use of leghold traps and one by shooting. One of the trapped coyotes was found to be suffering from distemper. No further coyote attacks on humans were reported.

<u>San Diego, San Diego County, 1988</u>

A 24-year-old woman was approached and bitten by a coyote in an urban area of San Diego, while talking on a cellular phone in her backyard. Neighbors in the area reported recent sightings of coyotes boldly wandering in the area. A resident two houses away had lost a small dog to a coyote, and three or four cats in the neighborhood had similarly been taken. The ADC Specialist who responded to the complaint removed the offending coyote within less than a week by use of a leghold trap in the woman's yard. No further incidents were reported.

<u>Reds Mountain Campground, Madera County, 1990</u>

A 5-year-old girl in a sleeping bag was attacked and bitten during the early morning of June 29, 1990. The campground is about six miles west of Mammoth Lakes in the Inyo National Forest. Adults sleeping near the child, awakened by the child's screams, saw the coyote retreat. The child sustained a severe scalp laceration and several canine puncture wounds, and she received medical treatment. USDA-ADC personnel and others, working in cooperation with U.S. Forest Service and Park Service personnel, shot four coyotes in the vicinity. Interviews with park rangers and campground residents revealed that people in the area had been feeding coyotes. It was also noted that skiers at Mammoth Mountain, only a few miles away, had been feeding coyotes during the winter ski season. Observers noted that the coyotes would readily approach people for food, showing little fear. The investigation also revealed two previous biting incidents had occurred the same day. One person was bitten on the foot through a sleeping bag, while another individual was bitten on the hand; no other details of these incidents were documented in the records at California's USDA-Wildlife Services office. Forest Service and Park Service officials quickly instituted an educational program to stop visitors from feeding coyotes or other wildlife, or leaving food available. A Park Service official noted that the shooting effort immediately instituted a fear of humans in the remaining coyote population.

Laguna Nigel, Orange County, 1991

This case involved a pet owner who had his poodle taken out of his arms by an attacking coyote. The poodle was not saved. Coyotes had been seen in early and late mornings chasing and killing cats and rabbits in the neighborhood prior to this attack. After this incident, several coyotes were taken with padded leghold traps and euthanized, and there has been no re-occurrence of problems at this site (the 1995 incidents in Laguna Nigel were in a different neighborhood and are considered unrelated).

San Clemente, Orange County, 1992

The attack on a child was preceded by three to four weeks of coyote attacks on two dogs and six house cats, as reported to San Clemente Animal Control (Gene Begnell, San Clemente City Fire Department/Animal Regulation, pers. comm.). All of the attacks were in the same residential area, and coyotes were readily seen day and night, especially on trash collection days. One licensed childcare facility reported having to bring children inside from the rear yard, which faced a common landscaped slope, due to a coyote stalking the children's play area (Figure 1). This facility was about one-quarter mile from the nearest wildlife fringe area. The 5-year-old girl who was bitten attempted to escape from the coyote by climbing onto a swing set. The child's mother scared off the coyote, but the girl sustained several bites on her back. Police tried to shoot coyotes for several nights after the child was attacked, but they failed to take any coyotes. Two coyote dens and numerous bedding areas were found in the landscaped slope areas throughout the development. Trapping was conducted for 10 days by APM, resulting in removal of six coyotes, primarily adults. Another two coyotes were shot by APM biologists. Coyotes have not been a problem since the control program. When seen, they are now on outer fringe areas and run to avoid humans.

Figure 1. Coyotes frequented an area near a childcare facility, San Clemente, 1992.

Newport Beach, Orange County, 1994

Neighborhood attacks on domestic animals and pets over a six-month period preceded the July 1994 incident where a mother rescued her 2-year-old child that was being stalked by a coyote. Neighbors near Upper Newport Bay reported seeing coyotes, with no apparent fear of humans, foraging in neighborhoods and yards during daylight hours. The mother screamed and ran out of the house to rescue her toddler, after looking through a window into the backyard and seeing a coyote apparently crouched for attack, five feet away from her son. She had lost 23 chickens and 22 rabbits to coyotes in her backyard during the preceding months, and a neighbor's German shepherd had been killed by coyotes. City animal control authorities recommended residents take steps to remove coyote food sources, and they initiated an effort to shoot the offending coyotes.

Griffith Park, Los Angeles County, 1994 to 1995

These attacks began about four months after coyotes started to be seen making late morning and afternoon visits to turf and picnic areas. These early signs are consistent with numerous reports of increased activity in early summer when adult coyotes typically are hunting for their fast-growing pups. Reports of cats and rabbits being chased and eaten by coyotes on turf areas became common, as did the finding of remains of cats, skunks, and rabbits. About two months before the first human attack, picnic patrons began reporting coyotes begging for food, followed by reports of coyotes scaring people away from their picnic provisions. Five adults were subsequently attacked and bitten by coyotes in the park. Then, a 15-month-old child was bitten through a heavy jump suit and was rescued by the child's mother as the coyote attempted to carry the child away. The mother had previously chased the coyote away 10 to 15 minutes before the attack.

All of the attacks occurred within 100 yards of heavy brush habitat, usually on lawn areas. Only two of the attacks appear motivated by hunger—the smallest child that the coyote tried to run off with, and the June 1995 attack on the woman who was preparing food. Most of the other victims were men sleeping on various lawn areas, some as close as 10 to 12 yards from brush, but most were from 25 to 150 yards from brush. All the attacks occurred between noon and 5:00 p.m., and resulted in bites to the feet or legs. As noted on the Park Incident Reports, most of the attack victims had bare feet, a possible contributing factor that warrants further study.

Site evaluation and ranger interviews identified two primary activity areas. It appeared likely that two coyote family groups were causing the problems. Tracks indicated three to four sizes of coyotes were active in each area. Dense brush covered the canyons and hills in these areas. Mountain shrub and brush areas adjacent to attack sites were searched for dens, to determine if the attacks were associated with protective territorial behavior in the March to July incidents. However, all dens found were located more than 200 yards from the attack areas, and numerous well-used hiking trails were much closer than the attack areas. Many coyote trails and bedding areas were found; they were littered with chicken bones, food wrappers, and skunk, rabbit, and cat remains.

Safety warnings were posted and passed out to park visitors, requesting them to report coyote sightings, informing them to keep children close, and not to feed coyotes. Because many open and overflowing trash containers had been observed during the site evaluation, sanitation practices were initiated as recommended.

Since the coyotes' behavior represented an immediate danger to park visitors, a special team of APM wildlife biologist sharpshooters was brought in for several nights, after park closing, to focus on the target areas and problem coyotes only. Five older adult and three young adult coyotes were removed. The coyotes were called into safe shooting zones by use of recorded urban animal and baby-like sounds. The dominant adults were quick to react. Cage traps and cannon nets were also used. One juvenile coyote was cage-trapped using a chicken as bait in the trap. Coyote capture success is rare with cage traps, but the City of Los Angeles would not allow use of padded leghold traps. Since removal of these two family groups, there have been no further problems. Only one very wary coyote has been seen in the problem areas, even though there are many coyotes actively using the wildland areas of the park.

Laguna Nigel, Orange County, 1995

These problems started after coyotes were observed for several months on streets and in yards, in daylight and evening hours, and followed numerous attacks on pets. Coyotes fed out of pet dishes, and they commonly roamed the streets on trash collection day. After the two human bite cases, seven coyotes were removed by trapping. There have been no subsequent reports of human attacks or harassment. Occasional sightings of coyotes have been made at night recently, but they are still very wary of humans. Of interest was the location of the bite cases which, unlike all but the UC Riverside cases (below), occurred several blocks from canyons or native brush.

UC Riverside, Riverside County, 1995

On the campus of the University of California-Riverside (UCR), cat remains were found numerous times during the two to three months prior to the first attack on children. It was discovered that residents of the campus family housing area had been leaving feed out for feral cats. Coyotes were seen chasing and carrying off cats at night and early in the morning. By late spring, coyotes were observed feeding on cat food in the afternoon, and they were occasionally reported to chase joggers on rural trails. In June, three boys in the housing area were chased out of a playground by a coyote that eventually caught and bit a 7-year-old boy. Between the first attack at UCR (June 1995) and the second one (November 1995), adults accompanied the children to the playground, and most children stayed closer to home. Coyote activity increased during daylight hours on and near the campus. A coyote even appeared on a soccer field during a game attended by numerous fans. More joggers and cyclists reported being chased near a heavily landscaped area.

After the second child was attacked, a site evaluation revealed pet food left out for one or two remaining cats, and areas of exposed garbage and trash were identified. Numerous rabbit remains were seen around several shrub and lawn areas, and coyote feces were found to contain rabbit, skunk, roof rat, fruit, trash, and cat or dog food. Of necessity, shooting was restricted to a very limited area that was deemed a safe shooting zone, and which was out of public sight. Recorded urban animal cries, as well as the call of a distressed cottontail, were again used to attract the coyotes. Only two adult coyotes were taken using firearms. Leghold traps were successfully used to remove an additional five coyotes. Now, over two years later, no more attacks or harassment have occurred, even though feral cats have started to populate the campus again. No coyotes have been spotted on campus in daylight hours, but occasionally one is seen at a distance at night in the native plant garden area and in adjacent brush on the east side of campus. Some of the trapped coyotes came from the freeway right-of-way, and others traveled on the railroad right-of-way from wildland habitat about one-quarter mile (0.4 km) to the east.

San Juan Capistrano, Orange County, 1997

The Nichols Corning Institute, a large facility employing about 1,000 people, is located on 100 acres in a rural area about 10 miles from a densely populated development in San Juan Capistrano. When developed, the landscaping was designed to maintain as many native plants as possible, including dense chaparral and coastal sagescrub located about 20 yards from the buildings. A large pond with a sizeable adjacent lawn area was also established. Employees frequently ate on the lawn area and in their cars in the parking area, as well as on the patio and in an indoor lunch and break area. Coyotes were often seen in adjacent wildland areas or running from the lawn and pond areas to the sagescrub area as cars approached. They were increasingly visible for about a two-year period, and by spring 1996 they had become noticeably bolder. By late summer, coyotes were frequently seen in daylight hours as well as late evenings around the parking lot and landscaped areas. Occasionally, they were seen chasing rabbits, raccoons, and skunks. They began approaching employees who were eating lunch on the lawns or walking to their cars.

In early December, management became aware of the unusual coyote behavior and distributed a letter warning employees of the possible danger coyotes posed as a result of their loss of fear of people. The letter suggested methods of possibly changing the coyotes' behavior by not bringing food outside of the buildings, and by not putting discarded food in outside refuse containers. If the coyotes approached employees, they were to stop and yell at them to scare them away. The letter encouraged employees to report coyote sightings to security personnel, so that they could chase or harass them. Management wanted to alter the coyotes' behavior without harming them, if possible.

Unfortunately, these actions were too late, as the coyotes became bolder, even approaching the patio when it was full of people at noon, sending them all back into the buildings. The security guards and shuttle drivers picked up the pace of harassing coyotes whenever they were seen. However, as listed in Table 1, the first very aggressive attack occurred in January 1997. Two adult female employees were victims, one of whom was pulled to the ground by a coyote that bit her ankle twice. The two women yelled, hit the coyote with handbags, and finally escaped the attack by getting into a car. Within two weeks, nine employees had been attacked on sidewalks and in the employee parking lot.

A site evaluation and recommendation was done by APM on January 13, 1997. Selective shooting was recommended, due to the severity of the case, and because heavy rain at that time made trapping less feasible. Management was apprehensive of possible bad publicity from shooting, so they opted to delay until drier soil conditions would allow trapping to be initiated. Meanwhile, Orange County Animal Control had responded to the site several times between January 5 and January 16 but had failed to capture any coyotes. After the January 17 attack, shooting was initiated despite inclement weather, and two adult coyotes were taken. Two more people, both adult males, were attacked the following week, and shooting was again initiated when weather permitted. Three additional coyotes were taken in one night.

In this series of attacks, most victims had purses or backpacks that the coyotes may have associated with food, even though there was little or no food in the purses taken. The lunch pail one woman used in an attempt to defend herself was empty. Because no further sightings on the grounds occurred, nor was coyote sign seen on trails, subsequent trapping was not initiated. Coyotes have not been seen on the grounds since the three were removed by shooting, but they are often seen on adjacent roads and hills. The habitat was modified as recommended, with all refuse containers being removed from the parking lot and other outlying areas. Brush near the areas of human activity was thinned. If coyotes begin to prey on rabbits again, a rabbit exclusion fence may be erected. The senior author presented a wildlife training class to the employees, and the Institute prepared a wildlife information handout for its staff.

South Lake Tahoe, El Dorado County, 1997

These incidents are included because the events and observations that preceded the attacks were similar to the southern California cases. In February 1997, late morning coyote activity had been reported at a ski lodge parking lot and in nearby neighborhoods. A man was bitten while actually feeding a coyote in the parking lot of a ski lodge. A 4-year-old girl, Lauren Bridges (Figure 2), was attacked in the yard of a South Lake Tahoe residence where she was staying with her family. She was largely protected by the heavy snowsuit she was wearing, but she suffered multiple wounds to her face. Sixteen of the wounds required stitches. The coyote had to be pulled off the child by the father, and it would still not leave after being hit. It appeared to stay "locked on" its prey until it was shot by a sheriff. Coyotes had been fed by a homeowner within a short distance of the site of the attack.

San Clemente, Orange County, 1997

The attack did not result in an injury because the parents, who have been prevented from putting up a coyote-proof fence by their homeowners association, only let the 2-year-old child play outdoors when they were with her. The coyote boldly approached the child, who was with her father and another man working on a backyard deck. It was seen a few feet away in a "freeze mode," seemingly locked onto the child as a prey item, and crouched for attack when the father grabbed the child. Had the child moved, the coyote most likely would have attacked, since movement is a key stimulus for initiating attack (Lehner 1976).

Trapping was initiated by APM, and several coyotes were removed by use of traps in the same yard (Figure 3). A compost pile and vegetable garden in the yard were used by the coyotes as food sources. Most feces collected in the area had a high occurrence of seeds of *Ficus nitida*, a street tree that produces a mass of berry-sized fruit. In addition to plant material, fragments of house cat, cottontail rabbit, and small rodents, and pet food were found in coyote scats.

Figure 2. Four-year-old Lauren Bridges suffered multiple wounds to her face when attacked by a coyote in South Lake Tahoe.

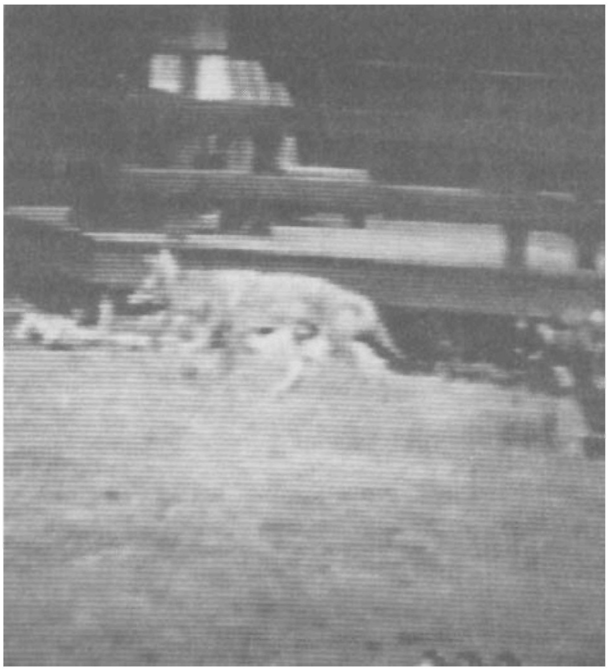

Figure 3. A coyote continued to visit the backyard of a San Clemente residence on a daily basis after it had stalked a 2-year-old child.

Pomona, Los Angeles County, 1997

The adult male attacked by coyotes on the Cal Poly-Pomona campus was on a walkway in a native plant area between buildings. He was carrying a small uncut watermelon. When he saw the two coyotes nearby, he began to run and then was attacked (Kimberley Platter, Chief, Public Safety, pers. comm.). He was bitten on the ankle but did not require treatment, even though he fell on some steps in his attempt to escape.

The number of confirmed human and pet attacks for the timeframe covered by this paper will undoubtedly increase as additional past incidents are brought to light. Additional incidents are also likely to occur during 1998. The senior author has initiated a survey on this subject, which is slated for completion in late 1998. Reports have been received, but not included here, of numerous other incidents of pets being torn out of owners' arms, cyclists being knocked over and/or chased, and joggers being nipped at by coyotes. The authors have included only reports that are documented by more than one reputable source, and preferably by a city, county, or state agency, or for which they have personal knowledge. Numerous animal regulation organizations and city authorities have declined to cooperate in gathering these data, in order to avoid adverse publicity towards their management of wildlife or the specific cities. Park rangers also reported a reluctance of some citizens to file reports after being attacked by coyotes (Hector Hernandez, Director of Park Rangers, City of Los Angeles, pers. comm.).

THE CHANGING ENVIRONMENT

Howell (1982) described development of urban sprawl into southern California mountain ranges, providing miles of urban interface with native brushy habitats. Many of the natural open space areas scattered throughout southern California are canyons that serve as seasonal drainage areas. Some of these canyons extend from the mountain ranges to the ocean, or to major riverbeds and flood channels.

Wildland areas of heavy brush (chaparral and mountain scrub) on the suburban edge commonly support wild mammal populations limited to deer mice (*Peromyscus* spp.), woodrats (*Neotoma* spp.), and a few other small rodent species. These areas are not particularly good habitat for the cottontail rabbit, pocket gopher, ground squirrel, or meadow vole. By comparison, landscaped urban and suburban areas with open, plush plantings of gazania, clovers, legumes, grasses, or various popular ground covers provide a luxuriant habitat for small mammals.

Urban and suburban landscapes used to take approximately 18 to 20 years to mature before commensal rats (*Rattus norvegicus* and *R. rattus*) had enough vegetative cover to become a problem. Now, driven by new landscaping ordinance requirements, increased affluence, and less patience, people create, in as few as five to six years, landscapes that are more attractive to commensal rodents and other wildlife than are native areas (Baker 1984). Community plans and government ordinances, for aesthetic and noise abatement purposes, have changed freeways and streets into beautiful, heavily landscaped areas. Many such areas become heavily infested with rabbits (*Sylvilagus* spp.), pocket gophers (*Thomomys bottae*), ground squirrels (*Spermophilus beecheyi*), and meadow mice (*Microtus* spp.) within one to two years after planting. All of these mammals are found in the coyote's native diet. Thus, these modified areas serve not only as wildlife corridors between wildlands and area of human habitation, but they are sufficiently rich in food, water, and cover to become permanent habitat for coyotes. Thus, coyotes are drawn into suburbia by rich, relatively stable food sources. Loven (1995) has documented similar utilization of resource-rich urban and suburban areas by coyotes in Texas, resulting in attacks on pets.

Other indications of the habitat richness the wildland-suburban interface provides to coyotes are home range size and density. Coyote home range size is a factor of the density of basic resources: food, water, safe harborage, and social needs. Howell (1982) described the suburban coyote's environment as follows: "He is virtually unopposed and supplied with a substantial food base." Home ranges of coyotes in the wild have been found to be 12.6 to 25 mi^2 (21 to 41.6 km^2) for males and 4.8 to 6.0 mi^2 (8 to 10 km^2) for females (Chesness and Bremicker 1974; Gipson and Sealander 1972). Shargo (1988) found the home range of coyotes in suburban Malibu to be from slightly under 0.5 mi^2 to nearly 1 mi^2 (0.64 to 1.44 km^2) and the 24-hour range of movement to be an average of 3.48 mi (5.8 km). These significantly smaller home ranges indicate that coyotes have found the urban environment to have plentiful food, water, and safe harborage.

In regard to density, Knowlton (1972) suggests that 0.5 to 1.0 coyotes/mi^2 (0.2 to 0.4/km^2) is a good estimate for large wildland ranges. Others agree with Knowlton and give educated guesses of up to 5/mi^2 (2/km^2) for the best habitat. While good measures of coyote density in suburban southern California are not available, it may be inferred from the small home ranges seen by Shargo (1988) that coyote density is considerably higher here than in most other habitats. In the Glendale area, 55 coyotes were taken during control operations within one-half mile of the site where a coyote killed a 3-year-old girl, over an 80-day period in 1981 (Howell 1982). Obviously, immigration of individuals into vacant home ranges was occurring, but this is another indication of the ability of this type of habitat to support high coyote densities. The authors suspect that human alterations of the environment on the wildland-suburban interface can create 10 to 20 times the natural carrying capacity for coyotes, as compared to undeveloped sites. The urban fringe areas, which apparently provide the best coyote habitat, have become the location for most coyote-human conflicts. However, not all urban or suburban areas provide such desirable habitat. Few mid-city areas offer good habitat unless they contain large parks or other habitat islands.

URBAN COYOTE BIOLOGY, DIET, AND BEHAVIOR

Coyotes, which resemble small German shepherd dogs, vary in size and weight according to subspecies and locality (Bekoff 1977; Gier 1968), with individuals from northern or higher-elevation areas tending to be larger. The average weight of coyotes removed from the Glendale area of southern California in 1981 was found to be 27.9 lbs. (12.7 kg) for males and 19.9 lbs. (9 kg) for females (Wirtz et al. 1982). Twenty-five adult coyotes removed recently from several Orange County projects by Animal Pest Management of Chino, California ranged from 21 to 45 lbs. (9.5 to 20.5 kg). These coyotes from urban area problem sites were often heavy-appearing, had healthy coats except for two with mange, and seemed to be in good health. These weights are similar to the ranges reported for other coyotes in the western U.S. (Wade 1983).

Most of the wildland coyote's activity occurs at night and early morning hours, especially in the warmer part of the year. On colder winter days, coyotes may hunt throughout the day depending on food availability and the presence of humans. Coyotes in urban areas have been observed by the senior author, and by a number of persons interviewed, to actively feed in late mornings and afternoons. They find food items on streets (refuse, and fruit of street trees), in yards of residences (fruit, rodents, pets, and pet food), on golf courses (rabbits and ground squirrels) and in parks (pocket gophers, rabbits, meadow mice, roof rats, and food and garbage from picnickers). Many residents report coyotes habitually foraging for food every "trash day" (the day of the week that refuse containers are placed at the curb for collection) both at night and in early and late mornings. As Howell wrote, it was not unusual for early morning joggers and commuters to see one or more coyotes daily. Now, it is not unusual to see coyotes throughout the day in back yards, streets, parks and golf courses (Figure 4). In fact, many of the attacks described here have occurred in full daylight between 9:00 a.m. and 4:00 p.m. Most of the attacks have occurred within a few blocks of the urban fringe area where native brush is abundant or where open space, mandated to mitigate the negative affects of development, has provided brushy wildlife habitat islands surrounded by homes.

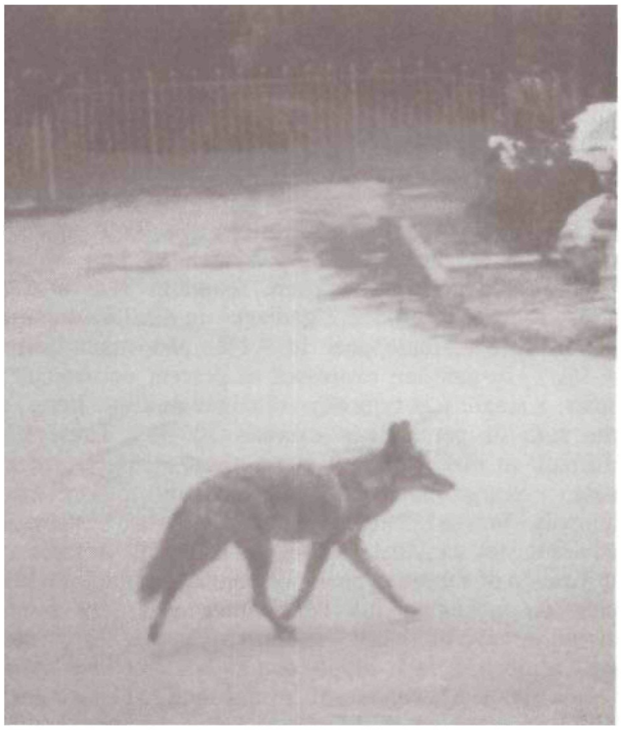

Figure 4. A coyote with little fear of humans is easily seen during daylight hours on an urban street in San Bernardino County, California.

The diet of coyotes in wildland areas has been found to consist of numerous mammals, birds, reptiles, arthropods, fruit, seeds, and greens from plants (Sperry 1941; Ferrel et al. 1953; Korschgen 1957; Gipson 1974). Most people who have researched the wildlands coyote's diet conclude that coyotes are omnivorous feeders and opportunistic predators (Van Vuren and Thompson 1982), using a wide range of foods depending on seasonality, behavioral imprints, parental influence, and the make-up of the surrounding environment. Others have observed that, in general, coyote food habits tend to reflect the composition of the local prey base (Fichter et al. 1955; Knowlton 1964). Typically, rodents and rabbits are dominant components of a coyote's diet.

A recent study in Arizona compared diets of coyotes frequenting rural versus suburban areas near Saguaro National Monument East (McClure et al. 1995). The investigators noted that suburban coyotes consumed human-related foods (e.g., pet food, bread, and other human-related items) as partial substitutes for the more natural foods eaten by their rural counterparts. The suburban coyotes also were seen to consume fewer plant items (e.g., mesquite pods, prickly pear fruits) year-round, and they ate fewer mammalian prey during the breeding and gestation seasons than did rural coyotes.

At least three studies have reported coyote diets in and around urban areas of southern California. MacCracken's (1982) study site was a semi-rural area on the edge of El Cajon, a suburb of San Diego. He found "garbage" (eggshell, plastic and cellophane, cloth, string, etc.) to total 16.7% of all items encountered in coyote scats (feces). Additionally, chicken comprised 8.3% of all items; and plant seeds, which he noted were primarily from melons, comprised 16.8%. While it is difficult to know whether the chicken and various plant materials were taken as refuse, he concluded that the occurrence of these items was a clear indication that coyotes were capitalizing on human-provided food sources.

Shargo (1988) reported briefly on food habits of coyotes in Malibu, a suburban area of Los Angeles County. Plant materials were found in 81.8% of all scats, rodents in 45.5%, "garbage" in 40.9%, domestic cat in 13.6%, mule deer in 9.1%, and small bird in 4.5%. His data are expressed as percent occurrence in scats; a single scat typically contained multiple items, so the sum of percentages exceeds 100%. Thus, it is difficult to make a direct comparison to MacCracken's data. Shargo noted that several radio-tracked study animals foraged extensively in suburban backyards adjacent to canyons, although different degrees of utilization of suburban areas were noted among individual animals. Among his conclusions was that human activities have produced a productive habitat for coyotes, with a plentiful food supply that is available year-round.

Wirtz (1982) conducted several food habits studies in different southern California habitats. Among other conclusions, he noted that urban coyotes killed during control activities in Glendale, California relied heavily on "garbage" as a food source, on the basis of stomach analyses he performed. In fact, on the basis of percent frequency of occurrence, 67% of food items fell into this category. While he classified such items as avocado, zucchini, and carrot as "garbage," it is impossible to know if suburban refuse was the actual food for these specific items, or whether coyotes were actively using urban gardens and fruit which fell from backyard trees. Scat analysis from two sites in Claremont, California (one urban, one rural) revealed that seasonal frequency of food items utilized was similar in the two habitats, in regard to fruits, woodrats, and meadow voles. However, urban coyotes in Claremont relied heavily on fruits and Jerusalem crickets in the fall and on pets and rabbits in the winter and spring.

Aside from animals' innate behavioral traits, learned behaviors assist in their adaptation to specific circumstances. Lehner (1976) discusses learned predatory behavior in coyotes, and he speculates about the role of observational learning and learning through communication. The coyote has been shown to adapt to a wide range of habitats. The authors speculate that its recent adaptation to urban and suburban habitats in places such as southern California has taken place over several generations, and such adaptation may involve learned behaviors passed from parent to offspring. If such adaptation occurs at different rates in various family groups, this could explains why there appear to be several behavioral "types" of coyotes using urban areas. Those most closely adapted to contact with humans may dwell entirely within the urban area, while others rest and den in the wildland fringe areas, entering the urban area for food and water. The less the fear of humans, the more often the coyote enters urban areas. There are also coyotes that apparently only enter seasonally as transient, non-territorial animals. Shargo (1988) and Wirtz et al. (1982) observed such behavioral differences in their study animals.

Wells and Lehner (1978) concluded that the coyote's primary senses used in locating prey (rabbits) were vision, audition (sound), and olfaction (smell) in this order of priority. All three senses are well developed in coyotes. Connolly et al. (1976) and others have demonstrated the coyote's innate ability to stalk, attack, and kill prey. Even coyotes born in captivity, or raised in kennels from the time they were pups, demonstrate stereotypic predatory behavior. Captive coyotes that had no previous prey-killing or hunting experience were shown to kill 30- to 70-lb. lambs when given the opportunity. Most coyotes approached the sheep and stalked them prior to attack. Fleeing sheep were always chased and usually attacked; Lehner (1976) also noted that movement of the prey, particularly attempting to flee from the coyote, is a stimulus that triggers an attack. The killing method on sheep was consistent, with each coyote clamping its jaws on the lamb's neck, eventually suffocating the sheep in manner mirroring that of wild coyotes (Connolly et al 1976).

In the wild, coyotes usually trot slowly and quietly while hunting. When prey are spotted, the coyote often freezes, and then pounces to attack. A "stalk and pounce" sequence is often seen when prey are small, and this behavior can be observed in coyote pups as young as 32 days of age (Young and Jackson 1951; Bekoff 1977, 1978). For larger prey or for prey farther away, they will quietly stalk until the right time for attack. They then often pursue the prey, biting the neck, and quickly stopping to hold the prey until no fight is left. When prey is located, coyotes appear to "lock" onto the target, switching from a foraging or ranging (travel) mode to a kill mode. It seems during this kill mode, when they are "locked-on," it is difficult to break the attention of a coyote or to dissuade it from attack. Researchers who have observed coyotes preying upon domestic animals have noted this singular focus on a selected prey, almost to the exclusion of extraneous stimuli (G. E. Connolly and F. F. Knowlton, pers. comm.). Those coyotes having less than the usual fear of humans would likely be even more difficult to chase away from prey. In the cases previously discussed, several coyotes that attacked humans were noted to remain close to the victim after being pulled or beaten off. When later shot by police, they were a few yards away and still in sight of the person who was attacked.[1,2,3]

CHANGING SOCIAL VALUES AND HUMAN BEHAVIOR

Most citizens enjoy watching wildlife, especially in natural settings such as national, state and local parks, wildlife reserves, and in other native wildland areas. In the past, most people held a proper respect for the danger posed by wildlife, especially the larger predators. However, attitudes of many people in today's society toward wild animals have changed from respect and fear to a certain reverence. This new attitude applies not only to large, dangerous predators, but even to small rodents that may carry disease.

Where coyotes have become a problem, trash handling is often poor. Most cities no longer allow plastic bags of refuse to be placed out for collection; however, the trash cans being used often are not tight-locking and are easily opened if knocked over by dogs or coyotes. At one problem commercial site, several large trash compactors were found to be leaking grease and other liquids and were frequented by coyotes.

Recycling is valued in today's society, but a compost pile was found to be a primary source of attraction to coyotes visiting one yard where a young girl was attacked. Coyotes also used an attractive koi pond next door for water and an occasional dinner.

A feral cat colony served as an attractive food source at one problem site. The coyotes eventually killed most of the cats and continued to feed on the cat food placed daily by well-meaning citizens. At many sites, cottontail rabbits were also a source of attraction to coyotes on park, golf course, and homeowner association common areas. Cottontail rabbits were formerly controlled throughout California by use of anticoagulant baits, but only two California counties still have baits labeled for this use. Cottontails are a highly attractive food source for coyotes. Public complaints about the use of poison bait to kill rabbits has led to a reduction in rabbit control, despite the serious damage they cause to landscape plantings (Richard LeFeuvre, Orange Co. Agric. Commissioner, pers. comm., 1997).

Many well-meaning citizens who feed wildlife, or who provide abundant resources for wildlife in their yards out of their desire to enhance viewing of wild vertebrates, may be doing serious harm. Such food sources can encourage populations of wildlife that far exceed an area's carrying capacity. Supplemental feeding also can change the animals' natural instincts relating to finding food, and change their behavior toward people. These conditions often lead to an increase in human-wildlife conflicts (Jurek 1997).

While people find it enjoyable to maintain bird feeders, even this activity can contribute to problems. Feed left on the ground or otherwise accessible will attract rodents and their predators, including coyotes. Many who feed birds do not realize how clean they must keep the area, or how to keep rodents out of the feeders. The authors have seen many rodent and predator problems caused by well-meaning birders. The senior author, responding to coyote complaints at various locations in southern California, has spoken to several homeowners who formerly fed birds and small animals until skunks, raccoons, and coyotes became a problem. Self-activated pet feeders and waterers are used by many until they learn about who's coming to the food or water besides the pet.

The most irresponsible human behavior contributing to coyote problems is actual feeding and watering of predators in urban, suburban, and park settings. In several parks and residential areas, people have been observed throwing scraps and bones to coyotes. Such activities can quickly habituate coyotes to dependence upon human-provided foods, as well as extinguishing coyotes' normal wariness of people. The feeding of coyotes is noted as a contributing factor to subsequent attacks that were described by Parker (1995).

Within the last two decades, the significant reduction in both coyote and rodent control programs in California, formerly provided by county agricultural commissioners, local health departments, and the USDA's Animal Damage Control (Wildlife Services), may be another factor related to the increase in coyote attacks on humans. These programs were often viewed as agricultural or rural services. Ironically, their demise has more significantly affected the urban citizens, who demanded the tax cuts, than the ranchers. Perhaps more important than the increase and spread of coyotes is a resulting change in coyote behavior: coyotes have ceased to regard humans as enemies, but instead perceive people to be a source of food. Coyote damage control programs have commonly relied on the use of leghold traps and on shooting; both techniques augmented and reinforced the coyotes' natural fear of humans. Curtailment of sport hunting and target shooting around urban and suburban areas has also reduced coyotes' opportunity to learn to be wary of humans. A basic law of nature is that animals must avoid destruction by their natural enemies (Young and Jackson 1951). It is adaptive for coyotes to maintain their fear of humans, as their only other natural enemies are the mountain lion (*Felis concolor*) and wolf (*Canis lupus*). Yet, in urban areas of southern California, this fear has at times been lost because of changing human behaviors.

INTEGRATED METHODS FOR WILDLIFE PROBLEM REDUCTION

Prior to initiation of any project to prevent or control coyote-human conflict, a well-qualified wildlife biologist should evaluate the situation to properly identify the problem and assure that all possible solutions are considered. The necessary initial information includes correct identification of the predator, presence of active coyote trails, prey base (from feces and other evidence), non-target activity, hazards, possible prevention practices, public attitudes, and time frames.

[1]Several news articles including the Tahoe Daily Tribune, South Lake Tahoe, California (February 18 & 19, 1997).
[2]Interview with Rebe McDaniel (March 1997), San Clemente, California, after daughter was attacked.
[3]Interviews with Douglas String (January 1997), San Juan Capistrano, California, and review of hazard/incident reports filed by attack victims and witnesses.

Public education is an integral component of programs to prevent or reduce human-wildlife conflicts. All public education materials should discuss how to avoid attracting wildlife (not just coyotes), and methods to maintain in wildlife a fear of people. The text should explain practical methods of using exclusion fencing, sanitation, and scaring or frightening techniques. Where coyotes have already become a problem, advice on how to react when approached or attacked by animals is important to include.

Sanitation is a key consideration in preventing modification of the coyote's inherent fear of humans. It must be stressed that it is critical to keep food and water inaccessible. Pet food must always be kept indoors or cleaned up after the pet has fed. "Animal proofing" is essential to exclude predators from composting sites and other attractive areas. Trash receptacles in parks or near urban fringe areas must be animal-proof. Tree fruit, pet food, and household garbage must be removed from yards and neighborhoods, and small pets must be kept indoors or in well-fenced kennel areas at all times. Limiting rodent and rabbit populations reduces the area's attraction to predators. Homeowners can exclude rabbits from rear fenced yards by installing rabbit fences of one-inch poultry netting, buried six inches into the soil and extending 30 inches or more in height. Electric fencing can be very effective to keep coyotes from coming over or under walls and fences, but they must be installed using very tight construction and with an effective grounding system.

When planning landscape projects, avoid ornamentals such as ivy, grape ivy, other vines, prostrate myoporum, or other such plants that produce fruit or that attract rabbits and rats. Maintain ground covers so they are kept low and thin. Keep skirts of shrubs and trees near wildland areas or near children's play areas pruned up several feet off the ground.

Many caring and well-meaning individuals unintentionally create human and pet safety problems by adding food to the wild predators' habitats. This action may change the social behavior of coyotes from being naturally wild and wary of humans, to actual dependence on them for food. Communities should develop ordinances against feeding wildlife, and they must back them up with enforcement. Numerous agencies and homeowner associations have developed effective rules to prevent wildlife feeding, including the maintenance of unsanitary bird feeders.

Scaring devices can be used when coyotes are seen. Check with local authorities regarding noise and weapons ordinances. A few of the successfully used items are include starter pistols, .22-caliber blanks, portable air horns, auto horns, propane cannons, halogen spotlights, slingshots, and rocks. Where legal, B.B. guns and low-powered pellet guns, using blunt pellets while aiming for the body rather than the head, can be effective. Rubber shot and slugs have also been used, but these can be dangerous and cannot be used where firearms are prohibited.

The City of Glendale has one of the best programs to date. Captain Michael S. Post of the Support Services Division, Glendale Police Department, runs the program. Captain Post's letter of introduction to citizens with coyote problems prudently states, "The prevalent scientific view prescribes educated co-existence as the only realistic long term solution for coyote-human conflicts." Citizens experiencing wildlife problems are sent an information packet including information on fencing, habitat modification including recommended sanitation practices, human and wildlife behavior, coyote biology, city wildlife anti-feeding ordinances, and the use of oleoresin of capsicum (pepper spray). Trapping and euthanasia are done only after citizens have tried all recommended methods to avoid the problem, or when public safety is immediately at risk. The program has been greatly successful in eliminating problem coyote populations by removing a few coyotes and reinstating the fear of humans and urban areas into the predators.

POPULATION REDUCTION AND BEHAVIORAL MODIFICATION

When use of the above-mentioned methods has not modified coyote behavior sufficiently to prevent conflicts, or when signs of human safety risks are developing, the following methods have proven to be effective. They can be used not only in removing the problem animals, but also in scaring and modifying the behavior of the local population. Coyotes not trapped or shot will then predictably move out of the area, and typically they will avoid humans for several years.

Leghold trapping using a No. 3 Victor Soft Catch® or other padded traps is quite effective. When modified with double swivels, shock springs, and a short chain (usually 12 to 16 inches total length), the humaneness of this already humane trap is increased. Pan tension devices, when installed and set for four pounds or greater, prevent capture of smaller species. Use of these modifications and expert trap placement reduces non-target capture and decreases stress on non-targets prior to their release from the trap. Traps may be checked twice daily in urban areas, where capture of non-target species is possible, and to reduce the chance of someone approaching a trapped coyote. The senior author is unaware that any domestic pets have been seriously injured by capture in these safer traps, in thousands of sets. The only injury that required veterinary treatment was a cat that the owner injured while removing it from the trap, instead of waiting for the biologist's assistance as had been recommended. Dogs are rarely found running loose in a coyote project area, and few cats are seen. Cats usually do not spring traps equipped with pan tension devices.

Of all techniques, trapping has the greatest observed effect of re-instilling the fear of humans in coyotes. When coyote attacks on pets have begun to occur in an area, it is imperative that the problem be corrected by use of trapping, so as to prevent escalating human-coyote problems including attacks on people. A seven to ten day trapping period using careful, selective trap placement in areas frequented by the offending coyotes is usually sufficient to re-instill their fear of humans. Eradication of all coyotes in the area is neither attempted nor necessary. The coyotes using the area often disperse after trapping and euthanasia of two to five coyotes; this is partially dependent on the size of the area, the number of coyote family units using the area, and the existing level of fear in the behavior imprint of the coyotes. It is harder to modify the behavior of coyotes that have been using urban areas for generations. Often this requires taking coyotes in greater numbers, and sometimes a second trapping phase is needed. All coyotes caught must be euthanized according to American Veterinarian Medical Association standards, as relocation is neither biologically sound, legal, nor humane. Further, there are legal liability issues involved when problem animals are relocated to a place where they may continue to be hazards to human safety. On all projects where trapping has been employed, coyote problems have not reoccurred for at least two years, usually longer. If other recommendations are followed and people do their part, trapping may only have to be conducted once in each problem area.

Cage traps are only recommended for attempting to capture sick or very young coyotes. Cage traps are ineffective at capturing most coyotes (Howard et al. 1985; Loven 1995; and personal experience). When coyotes and other wild animals are caught in cage traps, they are usually in much worse physical condition than those caught in soft catch leghold traps. Some cities in Los Angeles County, through experience, have found that leghold traps usually have to be employed if the goal is to capture coyotes. Only in instances of trying to capture starved or juvenile coyotes do they attempt to use cage traps, employing the services of the Los Angeles County Agricultural Commissioner.

Shooting is very limited in its feasibility in urban areas, and it must always be coordinated with local law enforcement agencies. The wildlife biologist's evaluation is especially important prior to shooting, and the biologist should use only experienced personnel on the project. Safe shooting zones must be identified, residents or property owners notified, and target animals and safe backgrounds checked by an experienced non-shooting safety team leader before shots are fired. Several varmint-type rifles and shotguns can be effectively used. There are new types of safer ammunition now available, so check with a knowledgeable supplier before purchasing ammunition.

DISCUSSION

Human-coyote conflicts have become common in southern California and in other areas. Attacks on humans by coyotes are no longer rare. They should be viewed as a real risk for children and adults, but they are preventable. The risks are greatest in suburban-wildland fringe areas and other brushy areas that are frequented by people. The authors believe state and local officials need to start collecting data on coyote attacks on pets and humans in order to better evaluate problems existing throughout the state. These data could also predict developing human-coyote conflicts, allowing for timely prevention in many cases.

Signs of coyote behavior that indicate a human safety risk appear to be quite clear, as evidenced by descriptions of the cases discussed above. These signs are, in order of their usual patterns of occurrence:

a. Increase in taking of pets at night
b. Increase in observance of coyotes on streets and yards at night
c. Daylight, early morning and late afternoon, observance of coyotes on streets and in parks and yards
d. Daylight observance of coyotes chasing or taking pets
e. Taking pets on leash and chasing joggers, bikers, etc.
f. Coyotes seen in and around children's play areas and parks in midday.

The motive for predatory behavior of coyotes is not always hunger (Connolly et al. 1976) or protection of dens, as demonstrated by many of the attacks discussed in this review. While the availability of food from humans in urban and park settings contributes to the attractiveness of the habitat to coyotes, their loss of fear of humans would not occur without a lack of aggression by people. Human activities, including organized trapping programs, sport hunting, and other activities that resulted in scaring coyotes away, reinforced the coyote's inherent wariness of people. But, changes in human attitudes toward the protection of all wildlife have resulted in coyotes, taking advantage of their opportunity to frequent prey-rich, human-created environments without harassment.

Authorities and citizens must act responsibly to correct coyote behavior problems before they become a public safety hazard. It is the experience of the senior author, and of persons interviewed, that when action is taken before pet attacks are a common occurrence, further problems can be avoided. However, this requires that aggressive actions and use of scaring devices be initiated promptly when coyotes are seen or heard close to residences. If pets are being taken frequently, or if other food sources have been used for a long period of time, leghold trap use is the best and longest-lasting behavior modification tool. An initiative measure submitted for the November 1998 California ballot will, if passed, ban or severely limit the use of leghold traps.

The City of Glendale demonstrates what a responsible and effective program can do. People are educated to better coexist with wildlife. When necessary, coyote behavior is modified by institution of a limited trapping program. Before the education and trapping control program was initiated, numerous human attacks from coyotes had occurred, including the tragic death of a child in 1981. Reports of humans being harassed within the city are now uncommon, and no bite cases have been recorded for more than 10 years due to the success of the program. Pet attacks were also very common, and pets were shown to comprise a measurable portion of the coyote diet (Wirtz et al. 1982). Over the last four years, a low incidence of pet attacks has been reported, averaging slightly more than four cats and one dog lost per year. This compares to much smaller communities that report 20 to 50 pet losses per year (Capt. Michael Post and Lenaee Dunn, City of Glendale Police Dept., pers. comm.).

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A TECHNIQUES MANUAL AND VIDEO FOR THE MANAGEMENT OF PROBLEM URBAN CANADA GEESE

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ABSTRACT: Social and management problems associated with urban Canada geese (*Branta canadensis*) are increasing in area, scope and magnitude. Although there are many articles on the management of urban Canada geese, none provide enough information for a reader to understand the impact geese have on different people, the ecology of the urban goose, evaluate the effectiveness of potential control options, choose appropriate management techniques, and then implement the chosen techniques. The authors present a manual and video, which in combination, they believe are not deficient in any of these areas. The video is intended to increase the awareness and knowledge of human/goose conflicts in urban and suburban environments. The manual covers the biology of Canada geese relevant to problem management in an urban setting and a comprehensive list of management techniques. Detailed instructions for implementation, permit requirements, sources of equipment and supplies, and a discussion of advantages, disadvantages, and characteristics, are included for each technique. To assist in choosing and locating appropriate techniques, quick reference summary tables are included.

KEY WORDS: birth control, Canada geese, habitat modification, hazing, removal, techniques manual, urban wildlife

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INTRODUCTION

Canada geese are perhaps the most widely recognized bird in North America. Geese flying in V-formation signal changes in season and for many people have come to symbolize nature and wildlife. Canada goose numbers were once reduced to the point of near elimination in most parts of North America by unrestricted egg harvest, commercial hunting, and draining of wetland habitat. Thanks to enactment of strict harvesting regulations, creation of protective refuges, changes in crop planting and harvesting techniques, and creation of large, open grassy areas, Canada geese have rebounded and are no longer at risk. This astounding recovery is partly due to the fact that Canada geese are opportunistic and readily adapt to urban and suburban areas.

Scientists recognize several "races" or subspecies of Canada geese. The geese most commonly found in urban areas during spring and summer are called giant Canada geese (*Branta canadensis maxima*) and are the largest of the races. Giant Canada geese have undergone a phenomenal population increase from only a few thousand in 1965 in all of North America (Hanson 1965) to an estimated 1.1 million in just the central U.S. in 1996 (Wood et al. 1996). This growth rate is not peculiar to North America; in Britain there has been an estimated 8% annual increase in numbers of Canada geese from 1976 to 1991 (Allan et al. 1995). Although a few geese may be desirable in a park, suburban pond, or backyard, such small populations increase rapidly and usually lead to problems which can be very difficult to control. Conflicts between Canada geese and humans in the urban environment have increased as goose populations have increased (Conover and Chasko 1985). Problems may be only a nuisance, such as droppings, aggressive behavior, and noise, or may represent a serious environmental threat or potential risk to human health and safety.

As a result of the increasing numbers of geese using urban areas, some major metropolitan areas in the upper Midwest and Northeast are faced with the increasing challenge of balancing Canada goose use of urban sites with human needs. As each municipality, wildlife agency, concerned citizens group or private organization has realized a human/goose conflict, they have discovered a single reference containing basic Canada goose management information is lacking. In some cases, local wildlife resources agencies have developed an informational bulletin or handout summarizing the dynamics of human/goose conflicts, outlining potential (and sometimes only favored) management techniques, and usually ending with phone numbers of the agency.

The authors have developed a techniques manual and video which will reduce the load on the resources of wildlife agencies to produce summary brochures or answer many questions over the phone. The combination of the video and manual will cover the problems associated with Canada geese in urban/suburban environments, Canada goose biology, state, provincial and federal regulations relevant to Canada goose management, techniques applicable to goose management in urban environments, and a wide list of suppliers.

The video is intended to increase awareness and knowledge of the human/goose problem, particularly the human dimensions components. It is 28.5 minutes long and is styled similarly to Public Broadcasting educational shows. The strength of the video is its ability to introduce the problems associated with human/goose conflicts to policy makers or general audiences. A summary of typical human/goose problems are introduced, alternative views from individuals with differing backgrounds are presented, then overviews of commonly used management techniques are shown.

The manual contains enough technical information that it may be used as a reference manual by professional wildlife biologists. However, it is written in a style that ordinary citizens can understand. The manual covers Canada goose biology as it relates to the urban/suburban environment including descriptions and general behavior, breeding behavior, nesting, molting, migration, and mortality. The Migratory Bird Treaty Act requires permits to harvest, or even handle, Canada geese. Information on U.S. and Canadian regulations and permits concerning Canada geese is provided, including some example permit applications.

A section of the manual is devoted to the ideas of matching the ecology of the geese with various techniques and the importance of developing an integrated management strategy. This includes establishment of management goals, publicity, combining techniques for enhanced effects, and potential problems and advice for field personnel when applying certain techniques.

The largest section, and the focal point of the manual, is techniques. This section represents a sincere effort to document the state of knowledge about urban goose management practices as it existed in 1997. The primary intent is to provide a list of techniques currently in use or previously tried to alleviate human/goose conflicts in urban areas. Some techniques are highly specialized, site-specific, or may best be used in combination with other techniques. Thus, no attempt was made to rate or scale the techniques from "best" to "worst." Techniques are categorized on the basis of impact on geese (from least to greatest); prohibiting feeding, habitat modification, repellents, hazing/scaring, birth control, and removal. Within categories, groupings are based on similarity of techniques. Each technique is fully described and cited to the original studies or for further details. Each technique is also related to the part(s) of the goose ecology it affects, and strengths and weaknesses discussed. If a technique's effect may be enhanced if used in conjunction with another, the combination is noted.

Following the techniques section is a continent-wide listing of commercial suppliers of the preceding techniques. The compilation was made from a thorough literature search, however, some suppliers were undoubtedly omitted. This table is provided as a convenience, and no endorsement is implied for those included nor were any suppliers intentionally omitted. The final section consists of a summary look-up table for the techniques. Each technique is summarized by its strengths, weaknesses, qualitative cost estimates, timing and area of application, permits required for implementation, and a page number referencing its detailed description.

When these products are available, announcements will be made on The Wildlife Society (TWS) and WDAMAGE email lists and in the Probe and TWS Wildlife Damage Management Working Group newsletters.

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TWENTY-FIVE YEARS OF MANAGING BIRDS ASSOCIATED WITH BUILDINGS AT THE UNIVERSITY OF CALIFORNIA, BERKELEY

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ABSTRACT: Information concerning 19 species of birds associated with 28 buildings on the University of California at Berkeley campus has been collected for 25 years. Sixteen species are included under three minor associations (temporary roosters, building invaders, and species that nest on (or in) buildings in small numbers). Barn owls and ravens have caused intense, though localized problems. Two additional species (cliff swallows and feral pigeons) have caused major problems. Feral pigeons have caused the most difficult problems to resolve. Case histories are used to describe problems associated with these birds, and control strategies for them. Cooper's hawks have nested in central campus locations for the last four years and their contributions to pigeon control, interactions with campus buildings, and adjustments to their presence are discussed.

KEY WORDS: Avitrol®, birds, buildings, bird control, bird exclusion, chicken mites, Cooper's hawk, pigeon

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INTRODUCTION

The values and popularity of birds are well known and accepted (Booth 1983). Less appreciated are the problems and costs to humans and their activities by birds associated with buildings. Costs to birds (disruption of migration and mortality from collisions with buildings) are important, but not significant on the Berkeley campus and are not discussed in this paper. Based on the amount of resources required to resolve problems, 15 species of birds are of minor importance. Five of these species roost on buildings, four (three currently) are building invaders, and 10 nest on (or in) buildings in small numbers. Workspace outbreaks of chicken mites (*Dermanyssus gallinae*) have been associated with feral pigeon and mourning dove nests. Barn owls (*Tyto alba*) and ravens (*Corvus corax*) and have been sources of severe problems in single locations. Cliff swallows (*Hirunda pyrrhonota*), also a minor problem on some buildings, and feral pigeons (*Columba livia*) are sources of major problems in multiple locations. During the last four years the year round presence of Cooper's hawks in the central campus has eliminated the use of bait for pigeon control.

Species of Minor Importance

Roost on buildings

- Peregrine falcon (*Falco peregrinus*)
- Barn owls (*T. alba*)
- Burrowing owl (*Athene cunicularia*)
- Brewer's blackbirds (*Euphagus cyanocephalus*
- House sparrows (*Passer domesticus*)

Building Invaders

- Mourning doves (*Zenaida macroura*)
- Hummingbirds (unknown species)
- Brewer's blackbirds (*C. cyanocephalus*)
- Brown towhees (*Pipilo fuscus*)

Nest On (or In) Buildings in Small Numbers, No Complaints

- Kestrels (*Falco sparverius*)
- Barn owls (*T. alba*)
- White-throated swifts (*Hirundapus caudautus*)
- Black phoebes (*Sayornis nigricans*)
- Robins (*Turdus migratorius*)
- Starlings (*Sturnus vulgarus*)

Nest On (or In) Buildings in Small Numbers, Minor Complaints

- Mourning doves (*Z. macroura*)
- Barn swallows (*Hirundo rustica*)
- Cliff swallows (*H. pyrrhonota*)

Complaints and Nesting Sites Eliminated

- House sparrows (*P. domesticus*)
- House finches (*Carpodacus mexicanus*)

METHODS—MINOR PROBLEMS

The five species noted for roosting on buildings are included because of the considerable mess associated with their presence. Nothing was done about the peregrine falcon and the burrowing owl because they are protected species and though extremely messy, especially the falcon's feeding debris, they were in inaccessible locations. Besides, pigeons were a major source of food for the peregrine. Pellets and droppings from the barn owls are now in an out-of-the-way location that is not of concern, except as a source of class study material. The mess created by Brewer's blackbirds is widely dispersed and of noticeable, but minor, importance. House sparrows roosting on decorative brick extensions on the walls of Eshelman Hall create a mess, but less than that of the sticky repellent substances, and every couple of years the walls are power washed to remove the whitewash.

Building invaders can sometimes be removed by opening windows, darkening the room by turning off the lights, and flushed birds will fly out the open windows. Because doves and blackbirds fly to the upper parts of a room, they are not easily flushed out the open windows. They can be flushed and caught with a long-handled net in dim light after dark and released outdoors. Blackbirds are no longer a problem because the café where they roosted on a decorative wooden frame over the entrance, and where they frequently entered through the open doors has been closed. Towhees are easily chased out open doors, because they fly close to the ground. Hummingbirds were a problem inside the Math Sciences Institute. During hot summer days the doors at the ends of the hallways were left open to provide ventilation, and the birds were attracted to large, red fire alarm bells on the walls just inside the entrances. The campus fire marshal was consulted regarding code requirements for the color of fire alarms; there were none. The bells were painted white, and the hummingbirds no longer come inside.

No complaints have been received about the five species that nest on (or in) buildings in small numbers and no controls are used. Kestrels nest in a second store space between the ceiling and roof of a married student apartment. They gain access where a ventilation screen has been removed. Nesting kestrels are very noisy, but there have not been any complaints to date. The barn owl nest sits on a ledge, and aside from the whitewash, there is little visible evidence. Pellets and droppings fall into an unused nook. White-throated swifts nest in expansion cracks in Memorial Stadium, and are not noticeable. Black phoebes, a new resident in recent years, nested on three buildings in 1997. Robins mostly nest in out-of-the way locations and there have been no complaints. The starlings nest in holes, and the author is surprised that there have been no complaints from residents of the student apartments.

Minor complaints have arisen from a few barn swallows nesting on porch lights, and a few from cliff swallows nesting above entrances. Barn swallows are uncommon and the person who used to complain has retired; no one else has taken up the issue. Cliff swallows nesting above sites where droppings will not catch on the side of the building below, or where the droppings collect on the ground are almost never a source of complaints. A few nesting above a building entrance, or where an unsightly mess accumulates can usually be prevented from nesting by physical removal of the mud foundations by maintenance personnel. Mourning doves enter rooms through open windows. Usually the nest is removed and cleaned up after the young have fledged, and the window is closed. After the nest is abandoned chicken mites (*Dermanyssus gallinae*) may attack humans in the room. Chicken mites are easily killed with pyrethrin aerosols registered for space application in offices.

House finches and house sparrows nesting on a ledge provided on the inside of decorative columns created a racket that bothered researchers in the building. During the winter, nesting materials were removed and the gaps at the tops of the columns were sealed with patching concrete.

METHOD—SINGLE SITE PROBLEMS

Barn owls nesting in Memorial Stadium were welcomed, though messy. Initially the mess was mostly out-of-the-way and of little consequence. When a $300,000 elegant food stand was constructed in the stadium, white fecal smears on the decorative awnings and accumulations of owls pellets were distressing in the extreme. The problem was resolved by glazing the openings to the outside. The opening under the owl nesting ledge remains open, and they rarely venture inside to the food stand. The problem has largely been abated.

In the last few years ravens have immigrated onto the campus. The Life Sciences Addition is an energy efficient building with "silvered" windows. Ravens see their mirrored image in the windows and attack. They severely scratch the Lexan panes and frighten the occupants of the rooms inside. A solution to this problem is still being sought.

METHODS—MAJOR PROBLEMS

Cliff swallows and feral pigeons are sources of the most serious bird problems on buildings. Cliff swallows nesting on buildings adjoining swimming pools create a slippery mess and a potential source of pathogens (Weber 1979), and nesting near observatories can befoul telescope lenses with their droppings. In these locations the nests were removed and sticky repellents were applied. The sticky repellents are messy, but tolerable compared with the mess from the nesting swallows. On the west face of the Lawrence Hall of Science, a three-story man-made cliff, high on a hill above the Berkeley campus the visual impact of the sticky repellents is not acceptable and the newly started nests are removed by building maintenance personnel each season until the swallows give up, an expensive, but effective solution.

Pigeons are the major pest species. Problems associated with pigeons on buildings are from droppings, noise, ectoparasites and animal rights activists. Droppings create potential health hazards from the pathogens that they contain (Weber 1979). They are expensive to clean up, and accumulations of pigeon droppings are a major breeding source of little house flies (*Fannia canicularis*) in cities in the San Francisco Bay Area (Poorbaugh 1990). People slip and fall on slippery accumulations on porches, and the acidic droppings even erode stone window sills. Noise from nesting and courting birds is disruptive for nearby office workers, and ectoparasites, chicken mites, often invade adjacent workplaces.

Controls used for pigeons on the UCB campus involve exclusion, baiting (now much more limited than in the past because of the presence of raptors preying on the pigeons), and trapping. Exclusion is used where possible, because it provides the most cost effective, long-term benefits. Exclusion measures used are netting and elimination of nesting and roosting ledges. Baiting with Avitrol® has been used on buildings where exclusion is not possible and to eliminate resident birds that "hang around" after exclusion has been completed. Trapping is still being used in one location where non-target racing pigeons would be affected by baiting.

Exclusion with netting has been used at two sites, Hearst Mining Building and the Banway Building. Hearst Mining, a four-story building with decorative beams under an overhanging roof, is on the national historic building registry. Few buildings have been better constructed for the shelter and propagation of feral pigeons. Pigeons have been trapped on the roof for several years since 1973, but this had to be given up because the traps could not be protected from vandals. It took over 10 years of complaints about bites from ectoparasites, people falling down the front porch stairs, and a number of costly cleanings of the window sills before campus architects would relent to having the beams covered with black, nearly invisible plastic netting. The Banway Building is seven stories and has an outer wall of decorative blocks. Each floor has a three foot wide porch between the decorative block wall and the outer wall of the offices. Pigeons were nesting and roosting on this porch. Office workers were complaining about the mess, noise (from squabs and adults), and ectoparasites that covered their walls and furniture, and bit some of the employees. Wire mesh screen was installed on the inner face of the decorative blocks. However, the problem persisted in one location. There was a hole in a corner of one of the porches that a pair of pigeons continued to nest in. Removing the young, treating the nesting cavity with a pyrethrin aerosol, sealing the entrance, and space treating the adjacent offices with the pyrethrin aerosol ended the complaints.

Exclusion by ledge elimination has been used at three sites. In two of these buildings, steeply sloped (Courtsal 1983), smooth patching concrete was used to cap protected flat ledges used for nesting and night time roosting. Flat-topped light fixtures hanging in a passage way at one of the sites were used for roosting. "Dunce cap" tops were added to these fixtures. In the third building, Sproul Hall, an exposed third story ledge over a plaza feeding area was used for loafing. Sproul Hall is covered with glazed sandstone that resembles granite. To refinish and protect the decomposing glaze this building was sprayed with seven layers of acrylic and epoxy polymers (Hitchins America, Inc.) that provided a smooth, self-cleaning, slippery surface that the pigeons no longer landed on.

Baiting with Avitrol® has been used on six buildings (Memorial Stadium, Martin Luther King Student Union, Barker Hall, Life Sciences Addition and Evans Hall). Whole corn is used for prebait and treated bait (Jackson 1991). All baiting has been done on rooftops. The size of the bait and locations (three to 12 stories high) have tended to exclude non-target birds species. Baiting was done as soon as the first pigeons were noticed (before the birds were numerous enough for people to notice and start feeding). However, four years ago, and each year since, Cooper's hawks have nested on campus. They actively pursue and capture pigeons. For the last four years pigeon carcasses have also been found on the roofs of Barker Hall and the Life Sciences Addition that appear to have been preyed upon by a raptor. There is a small room on the LSA roof in which the pigeons can hide. The access points are being screened, and all areas of the roof will then be accessible to raptors. Because of concerns about the potential secondary hazards of Avitrol® baits (Holler 1982) baiting has been stopped on the central campus area.

Memorial Stadium has an internal maze of structural steel beams that cannot be practically modified to exclude pigeons. However, the stadium is not close to a source of immigrant birds, and it has only been baited once in the last 10 years.

Martin Luther King Student Union is between Upper and Lower Sproul Plazas. There is a large flock of pigeons that is fed three blocks away at People's Park and, in the past, a small group of immigrants would appear on the Student Union. If allowed to remain, they would attract others, and people would start to feed them. More would be attracted, and they would start to nest in the open-ended, fluorescent light fixtures at the northeast corner of Lower Sproul Plaza. Additional risks were posed by animal rights groups which placed informational exhibits and tables on Upper Sproul Plaza within view of the bait placement site. Recently, the historical pattern of flock development has changed. The birds come and go, and a Cooper's hawk has been seen in the area. This is close to the hawk nesting sites. If the pigeon problem increases, trapping may again be used.

Barker Hall roof has shelter, water, and grit-sized aggregate. It is also the location of a high-tech biohazard containment laboratory and is close to sources of immigrant birds (downtown Berkeley and Ohlone Park). The roof, and that of the Life Sciences Addition, has an open center with shelves of parallel hung pipes, ventilation fans and ducts placed under a 10 foot wide overhang around the outer perimeter. Pigeons were also using a storeroom which had an open sliding door and no screen door. Installation of a screen door eliminated pigeons in this room. However, the birds cannot be excluded from the rest of the roof area without interfering with access for stationary engineers and other maintenance workers. In this location bait was used two to three times per year. Then a nesting site was found hidden under a large ventilation duct. After the nests were cleaned out and access screened off, the problem almost disappeared. Now and again a raptor-killed carcass is found.

Evans Hall is a massive concrete-walled cliff rising from the campus. It was designed with slanted window ledges, and it can be used as an example of how window ledges should be constructed to prevent bird problems. However, the top floor has porches on the east and west sides that extend the length of the building. The porches are covered, but open on the sides and provide wonderful views. Little used picnic furniture and planter boxes were used by pigeons for nesting, and the mathematicians and computer scientists who also occupied the top floor complained about the mess and the incessant cooing. The picnic furniture was removed, bird netting was placed over the planter boxes, and baiting was used to remove the site loyal birds (Jackson 1991). The site remained attractive, and baiting once or twice a year was used to remove new immigrants. No new immigrants have appeared since the Cooper's hawks started to hunt in the area.

The only location where trapping is still used is on the roof of the Marchant Building. This former manufacturing plant covers an entire city block, and after the university acquired Marchant, the fourth floor was rented to a biotechnology company in a joint venture. A flock of several hundred birds used to live on the roof, roosting and nesting in an unused cooling tower, and feeding on broken pie crusts that were tossed on the sidewalk across the street at the Saint Francis Bakery. The conservator of the Campus Herbarium, also housed in the Marchant Building, requested that the bakery no longer put out the pie crusts because the odors were attractive to herbarium (also called cigarette) beetles (*Lasioderma serricorne*) from several miles away. The bakery stopped putting out the broken pie crusts. The cooling tower was cleaned up and removed by a contractor, and the remaining flock was baited. After several months a flock of 30 birds suddenly appeared after a baiting program at a horse track several miles away. Staff members of the biotechnology program were concerned about pathogens vectored by pigeons and upset that the pigeons were roosting over the ventilation supply intake and that droppings were collecting on the vents. The area was baited again and caused some mortality in a newly started nearby racing pigeon flock. To prevent further problems a joint program was established. The Pest Management Program staff supply the traps, bait and advice; the Biotechnology staff members bait the traps whenever new pigeons appear on the roof. The staff members notify the pigeon racer whenever birds are trapped, and he picks them up and removes them. Aggregate on this roof is mostly larger than ¼ inch and is not suitable for grit.

DISCUSSION

Management of birds associated with buildings in the UCB program begins with an assessment of which control measures can be practically and legally applied. Redesigning buildings to exclude birds by screening, eliminating roosts, or eliminating the attraction (painting red fire alarm bells white), eliminating an attractive food source (broken pie shells) is preferred to shorter-lived treatments. Sometimes sticky bird repellents are used where the messiness is not objectionable. Where it is objectionable, active nest removal by building maintenance workers has proven effective, but expensive. Baiting has been used to control feral pigeons where habitat modification is not practical, and baiting has been an essential part of the program in the past. With the arrival of Cooper's hawks, the use of bait has been almost eliminated because of the potential risk to the accipiters (Holler 1982). This poses a potential problem because the Cooper's hawks may not provide as effective control, or control that is not effective enough. Pest Management is having building modified (LSA) to maximize accessibility of the pigeons to the raptors.

UCB Pest Management provides short-term services (evaluations and recommendations for redesign, application of repellents, and minimal baiting). More labor intensive controls (active nest removal and trapping) are provided by maintenance and support staff members on site.

In the past, early population control, largely through baiting, enabled efforts to be centered on the most attractive sites for the major problem species; feral pigeons. There are a number of additional sites that would provide additional protected roosting and nesting sites if the population were higher, and birds were forced into less attractive, but perfectly suitable locations. At this time predation by Cooper's hawks has supplanted the baiting program.

Blueprints for new buildings are reviewed and the author has had some success with campus architects in developing criteria for preventing the use of pest-inducing designs. However, the goals of people who use and maintain structures are usually in conflict with the short-term benefits of selecting the lowest bidder and bringing a contract in on time and at the least cost. This conflict is much broader than pest prevention and poses profound fundamental concerns in a future of declining operational funding for the University.

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STATUS OF APHIS VERTEBRATE PESTICIDES AND DRUGS

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ABSTRACT: The Wildlife Services (WS) Program manages wildlife/human conflicts by using an integrated approach employing some vertebrate pesticides. These are used in such small quantities that private industry cannot afford to register and produce them profitably. On behalf of WS, the Animal and Plant Health Inspection Service (APHIS) maintains about 30 federal and state pesticide registrations, containing seven active ingredients, with the U.S. Environmental Protection Agency (EPA). These include: the Compound 1080 Livestock Protection Collar, DRC-1339 Concentrates (Starlicide), Gas Cartridges (carbon and sodium nitrate), the M-44 (sodium cyanide), and a number of baits and concentrates containing Strychnine Alkaloid and Zinc Phosphide. In 1988 Congress amended the Federal Insecticide, Fungicide, and Rodenticide Act, requiring reregistration of almost all older pesticides. Reregistration had an extensive impact on the WS Program. Over 400 studies, with an estimated cost of about $14 million, were requested by EPA for APHIS products. Through negotiations with EPA, repackaging of old data, and obtaining data waivers for inappropriate studies, National Wildlife Research Center (NWRC) and APHIS personnel reduced the data requirements to about 250 studies costing $3 million. In addition, the NWRC managed three Consortia that generated funds and data to maintain Starlicide, strychnine and zinc phosphide products held by APHIS, private industry, and state agencies. APHIS is now entering the final stages of reregistration. Carbon, sodium nitrate, sodium cyanide, Compound 1080, and Starlicide have been reregistered. The Reregistration Eligibility Decision (RED), with an appended product-specific data call-in notice, was received for strychnine in March 1997 and the remaining data are being generated. Reregistration of zinc phosphide is expected sometime in 1998. In addition, APHIS now maintains four products for the WS Program with the U.S. Food and Drug Administration (FDA) under Investigational New Animal Drug (INAD) permits. These include alpha-chloralose (a capturing agent), the Tranquilizer Trap Device (TTD) containing propiopromazine HCl (to sedate animals held in leghold traps and snares) and two immunocontraceptive vaccines, porcine zona pellucida (Zonacon), and gonadotrophin releasing hormone (Gonacon) for contracepting deer and other wild animals.

KEY WORDS: pesticide, drug, registration, wildlife damage management, Wildlife Services

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INTRODUCTION

Wildlife damage management is an important part of the wildlife management profession that is conducted on a national level by the U.S. Department of Agriculture (USDA)/Animal and Plant Health Inspection Service (APHIS)/Wildlife Services (WS) program. The WS program is directed by law to protect American agriculture and other resources from damage caused by wildlife; WS has personnel in most states that provide both technical assistance and direct control of damage.

Wildlife damage managers are called upon to resolve a broad range of problems caused by wildlife. Determining the volume of wildlife-caused losses to agricultural products and other resources is difficult, and definitive information is not available. However, available estimates are that wildlife-caused losses have increased from 1957 to 1987 (Conover and Decker 1991), and approach $3 billion per year (Conover et al. 1995). Wildlife sometimes cause significant damage to agricultural crops and livestock, rangelands, forests, private and public property, other wildlife and their habitats, and urban and rural structures. Wildlife can also threaten human health and safety.

Prevention of wildlife damage may involve use of a variety of pesticides, drugs, and vaccines, including anticoagulant and acute toxicants, fumigants, repellents, frightening agents, aversive conditioning agents, immobilizing agents, contraceptives, and use of herbicides to alter habitat. The Wildlife Services program registers some pesticides with the U.S. Environmental Protection Agency (EPA) and receives authorizations for drugs and vaccines from the Food and Drug Administration (FDA). This manuscript will provide an update on the status of APHIS registrations and authorizations.

REGISTRATION OF PESTICIDES IN THE UNITED STATES

In the United States, federal regulation of pesticides began with the Insecticide Act passed in 1910, which made it unlawful to sell adulterated products (Bean 1977). The primary purpose of this act was to protect purchasers of insecticides and fungicides from fraud, but the act contained no provision for registration of pesticides prior to sale (Fagerstone et al. 1990). After World War II and the concomitant development of many new pesticides, the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) was passed by the U.S. Congress and registration of pesticides was first required.

In the past 25 years, significant changes have occurred in the regulation of pesticides. FIFRA was administered by the U.S. Department of Agriculture until 1970 when increased public awareness over environmental issues, such as large-scale use of pesticides like DDT, resulted in the creation of the EPA. A major revision of pesticide regulations occurred in 1972. Prior to 1972, FIFRA regulations emphasized pesticide efficacy; after

1972, the focus of regulations shifted to reducing risks to humans and the environment. The 1972 FIFRA amendments mandated that all pesticides must be reregistered within five years and that basic toxicity data must be submitted to the EPA for each chemical. Under the process established in 1972 and refined in subsequent amendments (Fagerstone et al. 1990), Registration Standards and Data Call-Ins were issued to establish data requirements for about 200 pesticides of greatest concern to EPA. By 1987, despite submission of large quantities of data by registrants, only four chemicals had been reregistered. Public pressure to speed up the reregistration process prompted the U.S. Congress to pass the 1988 Amendments to FIFRA ("FIFRA 88"). FIFRA 88 has had a broad effect on pesticide manufacturers, registrants, and users in the U.S. and other countries.

Under FIFRA 88, all pesticides containing an active ingredient first registered before November 1984 were required to be reregistered within a nine-year period. In 1988 approximately 600 groups of related pesticide active ingredients, representing 1,150 active ingredients in 45,000 formulated products, required reevaluation. FIFRA 88 specified a five-phase Reregistration process (Fagerstone et al. 1990). Phase 1 was a listing of the active ingredients of the pesticides for which reregistration was required and was completed in October 1989. In Phase 2, registrants notified EPA of their intention to seek reregistration of their pesticides and committed to supplying data within one to four years. Phase 2 was completed in 1990. During Phase 3, registrants submitted the data to EPA and identified known adverse effects of the pesticide. The reregistration process is now in Phases 4 or 5, depending on the pesticide. During Phase 4, EPA reviews submitted data and issues Data Call-Ins for additional data. Phase 5 involves the final review of data by EPA, followed by a regulatory action (such as reregistration or cancellation).

FIFRA 88 suspended all previously required fees and established two new types of fees to fund the reregistration process. The reregistration fee is a one-time fee of between $50,000 and $150,000 split among all the registrants of each active ingredient according to their share of the market. Annual maintenance fees were also assessed for every technical and end-use registration. In 1997 this fee was set at $700 for the first registration held by a registrant and $1400 for each additional registration.

FIFRA 88 also greatly expanded data requirements. Data requirements for most vertebrate pesticides fall into several broad categories (Fagerstone et al. 1990; Ramey et al. 1994): 1) Product Chemistry studies provide a profile of the physical and chemical characteristics of the pesticide product; 2) Wildlife and Aquatic Organisms studies determine toxicity to non-target species, primarily in the laboratory but also in actual field studies; 3) Toxicology or Human Health Hazard studies assess potential hazards to humans according to duration and route of exposure to the pesticide; 4) Environmental Fate studies monitor the movement, degradation and metabolism of the pesticide in soil, water and air; 5) Residue Chemistry studies are used to determine pesticide residues in plants or animals, allowing EPA to determine allowable tolerances on food items; and 6) Product Performance studies assess the efficacy of the pesticide.

FIFRA 88 has decreased the availability of chemical registrations. Increasing data requirements and the cost of generating those data have made it uneconomical for many registrants to maintain pesticide uses except those with large volume sales. As a consequence, registration cancellations have occurred at a high rate. Since 1988, more U.S. pesticide registrations were voluntarily dropped by manufacturers than were canceled by the EPA in the last 25 years. Estimates are that of the 45,000 Federal registrations held in 1989, approximately 19,000 were canceled that year, and 8,000 more since then, because either registrants failed to support the registrations with data and fees or because EPA has taken regulatory action to cancel registrations. Of the 611 groups of active ingredients registered in 1988, all active ingredients in 212 groups have been canceled.

REGISTRATION AND REREGISTRATION STATUS OF APHIS PESTICIDES

Most vertebrate pesticides are minor use pesticides compared to insecticides, fungicides and herbicides. Because the low volume of use cannot economically justify the cost of annual maintenance fees and data generation imposed by FIFRA 88, large numbers of vertebrate pesticides of importance to agriculture, the public, and to wildlife damage managers and public health personnel have been canceled or have had their uses restricted.

Wildlife Services manages wildlife/human conflicts by using an integrated approach that employs some of these minor use vertebrate pesticides, which APHIS has reregistered itself or has developed innovative ways to help registrants generate the funding required for reregistration. APHIS maintains registrations for seven active ingredients: Compound 1080, Starlicide, carbon, sodium nitrate, sodium cyanide, strychnine alkaloid, and zinc phosphide. APHIS also maintains about 25 to 30 individual end-use products, one Experimental Use Permit, and four vertebrate drugs and vaccines. The NWRC is responsible for meeting all data requirements imposed by the EPA for maintaining APHIS products. The APHIS Data Support Team in Riverdale, Maryland is responsible for administrative liaison with the EPA.

Reregistration has had an extensive impact on the WS Program. Over 400 studies, with an estimated cost of about $14 million, were originally requested by EPA for APHIS products. Through negotiations with EPA, repackaging of old data, and obtaining data waivers for inappropriate studies, NWRC personnel reduced the data requirements to about 250 studies costing $3 million. In addition, the NWRC developed three Consortia to generate funds to maintain strychnine, zinc phosphide, and Starlicide products held by APHIS, private industry, and state agencies. These Consortia have a combined responsibility of over 90 additional vertebrate pesticide registrations.

APHIS is entering the final stages of the EPA reregistration process for WS vertebrate pesticides. Five active ingredients have been reregistered and all data requirements (except for data required for the end-use products) have been met. Two products are still in the reregistration process. The following is a summary of the status of each technical ingredient.

Gas Cartridge (Sodium Nitrate and Carbon)

The Gas Cartridge is a fumigant cartridge containing two active ingredients, carbon and sodium nitrate. The Gas Cartridge is ignited, placed into a burrow or den, and all entrances are closed to prevent the escape of gas. Ignition produces high concentrations of carbon monoxide gas, a gas recommended by the American Veterinary Medicine Association's (1993) Panel on Euthanasia because it quickly induces unconsciousness without pain. No secondary toxicity exists with use of the gas cartridge.

APHIS maintains two Gas Cartridge registrations. The Gas Cartridge is widely used to control field rodents (Fagerstone et al. 1981; Matschke and Fagerstone 1984; Dolbeer et al. 1991) where they damage rangeland and agricultural crops, or carry plague. The Large Gas Cartridge is used to control coyotes (*Canis latrans*), red fox (*Vulpes vulpes fulva*), and striped skunks (*Mephitis mephitis*) in dens (Savarie et al. 1980; Ramey 1992a, b).

EPA originally requested 110 studies costing more than $2 million for reregistration of carbon and sodium nitrate. Many of which were waived, as they were not appropriate for these chemicals. However, since 1989, 24 studies were conducted for the Gas Cartridges and their active ingredients; use instructions have also been changed to provide protection for nontarget wildlife. The reregistration process has been completed for the Gas Cartridge.

Compound 1080

Compound 1080 is an acute toxicant that formerly had wide use as a predacide and rodenticide. Most predacide uses were cancelled in 1972 because of potential nontarget hazards, and rodenticide uses were canceled in 1990 because technical registrants did not submit adequate data in support of Compound 1080 to the EPA (Fagerstone et al. 1994). Currently, APHIS maintains two U.S. registrations for Compound 1080, Compound 1080 Technical and the Livestock Protection Collar (LPC), which is used to control coyote predation on livestock. The LPC is a rubber collar filled with a dilute solution of Compound 1080 and placed around the neck of a sheep in areas where coyotes are causing livestock mortality. The toxicant is dispensed as the coyote attacks the neck of the sheep and punctures the collar (Connolly 1990). Two collars are registered, a small one for use on lambs and kid goats, and a larger one for use on sheep and goats over 50 pounds.

Although EPA originally requested 55 studies at an estimated cost of nearly $1.5 million, APHIS received waivers for many data because Compound 1080 use in a collar around the neck of a sheep does not allow exposure to nontarget wildlife or the environment. Less than one pound of 1080 is used for APHIS collars each year. The reregistration of Compound 1080 has been completed and 40 studies were submitted to the EPA.

Sodium Cyanide

APHIS maintains a single registration for sodium cyanide which is used in the M-44, a spring-loaded device containing the toxicant that is placed in areas where coyotes, foxes, or feral dogs are killing livestock, poultry, or endangered species. An attractant draws the predator to the device; when the predator pulls the M-44, it receives a lethal dose of sodium cyanide.

Sodium cyanide in the M-44 has been reregistered by the EPA. APHIS submitted 29 studies out of the 56 originally requested by the EPA; waivers were granted for many studies because of the selectivity and limited use of the M-44.

Starlicide

Starlicide or DRC 1339 is a slow-acting bird toxicant. The technical product, Starlicide, is registered by PM Resources, as is Starlicide Complete®, a pelleted product for controlling starlings (*Sturnus vulgaris*) in feedlots. APHIS maintains five Federal registrations and several state registrations for field uses of DRC-1339 for controlling: pigeons (*Columba livia*) in and around structures when they cause nuisance or disease problems; blackbirds (*Agelaius* spp.) and starlings in livestock feedlots where they consume feed and spread diseases such as histoplasmosis; blackbirds, starlings, grackles (*Quiscalus* spp.), and brown-headed cowbirds (*Molothrus ater*) in non-crop staging areas associated with roosts; gulls (*Larus* spp.) to protect colonial nesting seabirds; and ravens (*Corvus corax*) where they are killing endangered species or livestock. The use of all APHIS registrations is restricted to Certified Applicators and WS personnel trained in bird control (or persons under their direct supervision).

EPA originally requested 68 studies at a cost of over $2 million for reregistration of Starlicide and DRC-1339. Because PM Resources does not sell enough Starlicide technical to support reregistration costs, APHIS and PM Resources combined their efforts and APHIS provided much of the required data to support field uses of this product. APHIS and PM Resources have jointly submitted 44 studies costing in excess of $500,000. Starlicide has been reregistered by the EPA, although labeling for some end-use products is still being negotiated.

Strychnine

Strychnine is an acute rodenticide widely used underground to control pocket gophers (*Thomomys* spp., *Geomys* spp. and *Pappogeomys* spp.), moles (*Scalopus* spp.) and some ground squirrels (*Spermophilus* spp.) to prevent damage to forest seedlings, agricultural crops, and home landscaping. APHIS maintains four registrations for control of pocket gophers using grain baits applied either by hand or with a burrow-builder.

In 1986 and 1987, EPA issued Data Call-Ins (DCIs) requiring technical registrants to submit data on toxicology, environmental fate, and efficacy. Because none of the technical registrants could afford to produce these data, a Consortium of private, State, and Federal registrants of strychnine was formed in 1988 to generate funds. The Consortium consists of 24 members, each of which contributed $3,000 in start-up fees, and also put in place a $0.50/oz. surcharge on sales of the active ingredient. The NWRC coordinates this Consortium, and has prepared all correspondence with EPA, conducted some studies, and monitored other studies conducted by contract laboratories. In October 1988, all strychnine registrants received Notices of Intent to Suspend from the

EPA because of noncompliance with the data submission schedule. Most registrants, including APHIS, believed they had complied and the Consortium requested an Administrative Hearing, which resulted in a 1989 Strychnine Settlement Agreement specifying new data requirements and due dates. Since 1989, the Consortium has submitted over 40 studies to the EPA to meet Settlement Agreement and reregistration requirements. The EPA issued the Reregistration Eligibility Decision (RED) for strychnine in March 1997. Based on the RED, registrants were required to complete an additional two studies for the technical product and four studies for the end-use grain bait products. One of these studies has been subsequently waived and another reduced in scope. Remaining studies will be submitted in 1998 to finish the reregistration process.

Zinc Phosphide

Zinc Phosphide is an effective acute field rodenticide that has been in use for over 50 years with very few non-target hazards. For many species of field rodents such as prairie dogs (*Cynomys* spp.) and ground squirrels it is the only pesticide currently registered for use. The Zinc Phosphide Consortium was formed in 1991, consisting of 16 registrants and coordinated by the NWRC. To provide funding to generate data to reregister the zinc phosphide active ingredient, the Consortium assessed each member a $2,000 start-up fee and placed a $4.00 per pound surcharge on sales of all technical zinc phosphide. The Consortium has submitted toxicology studies to the EPA, has met environmental fate requirements with data from existing literature, and has developed residue data to maintain registered crop uses. A RED is expected to be completed by the EPA in 1998 listing any additional data requirements for the active ingredient or the end use products.

STATUS OF APHIS DRUG AND VACCINE AUTHORIZATIONS

During the past five years, APHIS has begun working with the Food and Drug Administration (FDA) to obtain authorizations for the use of drugs and vaccines in wildlife.

Alpha-chloralose

APHIS has obtained an Investigational New Animal Drug (INAD) authorization from the FDA for use of the immobilizing agent alpha-chloralose to capture nuisance pigeons and waterfowl in urban areas (Woronecki and Thomas 1995). When fed to the birds on corn or bread, the drug causes sedation and the birds can be picked up to be relocated or euthanized. The chemical is available for experimental use from WS State Directors.

Tranquilizer Trap Device

A tranquilizer trap device (TTD) containing propiopromazine HCl has also been granted an INAD by the FDA for use to sedate coyotes, wolves (*Canis lupus*), and feral dogs caught in leg-hold traps. The TTD reduces the number of escapes from traps and reduces injuries and stress to trapped animals. This product will be available to WS State Directors this spring, as soon as a training program is established.

Immunocontraceptive Vaccines

Recent advances in immunology and molecular biology have made it possible to produce and administer genetically engineered contraceptive vaccines. In 1991, the NWRC began research on immunocontraception to inhibit reproduction in overly abundant wildlife species including deer, rodents, birds, and coyotes. Immunocontraceptive vaccines control fertility by causing the production of antibodies against reproductive tract proteins (eggs or sperm) or hormones associated with reproduction. The NWRC is working on two immunocontraceptive approaches, including production of antibodies against the zona pellucida (ZP, a layer around the oocyte), and against gonadotropin-releasing hormone (GnRH).

The zona pellucida is a glycoprotein layer around the egg that functions in the process of sperm/egg recognition. A ZP vaccine causes antibodies to be produced in the female to the ZP proteins; these antibodies bind to the ZP of the female's own eggs, blocking conception by preventing sperm penetration. In December 1996, the FDA assigned an INAD that will allow the investigational field use of ZonaCon Wildlife Immunocontraceptive Vaccine (containing porcine ZP) as an immunocontraceptive for wildlife species such as deer and coyotes. As a condition of the INAD, FDA requires that free-ranging animals be tagged to indicate that they cannot be used for human food. The FDA may also require that a site-specific Environmental Assessment be developed to address effects on wildlife populations and provide opportunity for public comment.

In March 1997, FDA established a second INAD for GonaCon Wildlife Immunocontraceptive Vaccine (containing GnRH) for wildlife species such as deer, coyotes, birds, and rodents. After receiving this vaccine, animals produce antibodies to GnRH, thereby reducing the action of GnRH on the pituitary. This then shuts down secretion of the pituitary reproductive hormones FSH and LH, preventing production of reproductive hormones in both sexes, and causing temporary (one to two year) sterility. The conditions of use are similar to those imposed by the FDA on ZonaCon.

The NWRC will soon be requesting a third INAD for a cholesterol inhibitor, DiazaCon (azacosterol HCl). This is an orally ingested chemical that inhibits production of cholesterol, preventing production of reproductive hormones and causing sterility. After ingestion of DiazaCon for a few days, animals remain sterile for two to three months. The product may be promising for seasonal breeders such as Canada geese (*Branta canadensis*).

ALTERNATIVE PESTICIDE RESEARCH

Whenever possible, wildlife damage managers attempt to recommend nonlethal solutions to wildlife damage problems. Increasing use is being made of immobilizing agents, repellents, and habitat modification. Herbicides have been developed by NWRC as a solution to prevent blackbird damage to sunflowers. Each summer, millions of blackbirds congregate in cattail marshes in Minnesota and the Dakotas. From these marshes the birds fly to nearby fields to feed on sunflower seeds, causing significant damage. Wildlife managers are now using the herbicide glyphosate (Rodeo®) to reduce cattail habitat, which in turn reduces blackbird concentrations and associated damage to sunflower fields (Linz et al. 1993). The resultant opening up of the marshes provides more waterfowl breeding habitat.

Gull populations have increased dramatically in the past few years. Roof nesting gulls cause structural damage to buildings, threaten human health, and pose hazards to aircraft at nearby airports. In urban habitats, nest disturbance will cause birds to abandon an area, however, disturbance may have to occur for three or more years before the gulls will abandon a nesting area completely. The NWRC has recently found that oiling eggs with corn oil or other oils kills the bird fetus and causes nest abandonment (Pochop et al. 1998). Corn oil is now registered for oiling both gull and Canada goose eggs.

NWRC is working with state agencies and private companies to develop and expand bird repellent products for dealing with agricultural damage. The NWRC conducted the initial evaluations and much of the efficacy research that led to registration with the EPA of methyl anthranilate (MA), a grape flavoring used in human foods such as grape pop and grape gum. MA is very aversive to birds as a trigeminal irritant that irritates the mouth as it is eaten. It is now registered by two different private companies. Current registrations include use on golf courses and parks to prevent Canada geese from feeding and fouling water supplies, use on standing water and on landfills near airports to repel birds from runway areas, and use on fruit crops (Cummings et al. 1992, 1995; Dolbeer et al. 1993).

The NWRC is currently working to restore bird repellent uses of Methiocarb (Mesurol®), one of the most effective bird repellents ever developed. Mobay Corporation previously registered Mesurol® for use on fruit and seed corn but discontinued these uses because of the low volume of use compared to the high cost of data requirements. NWRC is working with personnel from the Gowan Company, a small specialty pesticide producer, and has begun the process of obtaining EPA approval for registration of Mesurol® as an aversive conditioning agent and bird repellent on seed corn. An application for Mesurol® 75% Wettable Powder Aversive was made by APHIS in May 1997 that, when approved by the EPA, will allow use of Mesurol® in decoy eggs to deter ravens and crows from feeding on eggs of endangered and threatened species. In September 1997, Gowan submitted a Mesurol® 50% Hopper Box formulation for reducing bird damage to sprouting corn. If sufficient funds can be raised, Gowan and APHIS will attempt to bring back the registrations for soft fruits.

VERTEBRATE PESTICIDE RISKS

Most of the pesticides and drugs mentioned previously hold some potential risks to wildlife. However, risks associated with use of vertebrate pesticides are usually small, especially when compared to other pesticides. Several factors limit wildlife risks from use of vertebrate pesticides including: 1) safeguards provided by the registration process; 2) the low volume of use of these pesticides; 3) the limited area of use; 4) specificity in the action of these pesticides; and 5) the pesticides are targeted to specific animals or situations.

Registration Safeguards

The pesticide registration process lends safety to pesticide products by regulating use patterns of pesticide products, and ensuring that potential human safety and environmental health problems will be identified. In addition, for vertebrate pesticides, EPA routinely requires efficacy and nontarget hazards data not generally required for other types of pesticides.

Low Volume of Use

The low volume of use compared to insecticides, fungicides, and herbicides also provides a margin of safety for vertebrate pesticides. Total use of pesticides in the U.S. (for residential, agricultural, and other uses) averages approximately 1.2 billion pounds per year (Swanson 1990). Use in 1991 included 147 million pounds of fungicides, 495 million pounds of herbicides, and 175 million pounds of insecticides (Gianessi and Anderson 1993), about 70 percent of which was used in agriculture. National use of vertebrate pesticides in the U.S. for wildlife damage management is low, less than 1 million pounds. Annually only about 119,000 pounds of zinc phosphide active ingredient and 10,000 pounds of strychnine are used for control of field rodents, and predator and bird control products are used in even smaller amounts. The WS program uses only a small percentage of the pesticides used throughout the U.S. for wildlife damage management (ADC EIS 1994). Maximum annual rodenticide use by the WS program was less than 600 pounds, rodent fumigant use was less than 1,000 pounds, and fumigant use for coyote dens was about 1,100 lbs. Less than one pound per year of Compound 1080 was used and about 175 pounds of Starlicide. It is interesting to note that while <200 pounds of sodium cyanide are used annually as a pesticide in the M-44 for predator control, about 215 million pounds are used industrially each year in mining operations, often resulting in significant bird mortality at settling ponds and leaching heaps.

Use Sites Limited in Area

A third factor limiting vertebrate pesticide risk is their use pattern. Most are used in very limited areas, such as the Gas Cartridge (placed in burrows), and the M-44 (placed on paths frequented by predators).

Selectivity

Vertebrate pesticides also tend to be fairly selective. Rather than managing vertebrate pests on a species level, the trend in wildlife damage management is to deal selectively on a local basis with problem animals or problem situations. A good example of this is the Compound 1080 Livestock Protection Collar, which specifically targets only depredating coyotes.

FUTURE OF PESTICIDES

Use of toxicants is expected to decline in the future as alternate methods of reducing damage to crops, livestock, etc. are developed. Wildlife Services has placed increased emphasis on development of less toxic and less environmentally disruptive pesticide alternatives, including repellents, reproductive inhibitors, and "natural" products. Those pesticides that continue to be registered will face increasing data requirements as the EPA places increased emphasis on worker protection and develops new endocrine disruption and neurotoxicity tests. Emphasis will probably increase for development of IPM programs relying on scouting to determine economic thresholds of damage and on more accurate placement of pesticides.

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MAMMAL REPELLENTS: OPTIONS AND CONSIDERATIONS FOR DEVELOPMENT

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ABSTRACT: Repellents include chemical substances, visual displays, and sonic and ultrasonic deterrent systems. The use of electric shock also can be considered as a repellent category. Each of these categories is discussed, together with their respective utilities, constraints on their usefulness, and possibilities for future development. Economic considerations that may impede or expedite the development of new strategies are presented. Repellent effectiveness depends upon a complex of variables, including the palatability of protected and alternative foods, weather conditions, and the number of animals causing problems. Invariably, repellents are most useful when used as components of integrated pest management strategies.

KEY WORDS: acoustic, avoidance, electric, irritation, mammals, repellents, smell, taste, vision

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The number of non-lethal tools available for vertebrate pest control has actually diminished during the past decade (Clark 1998b). Paradoxically, the popular demand for such tools continues to increase. Repellents in particular are receiving widespread attention (Mason 1997), although for many products almost no data exist to support claims for effectiveness. This lack of empirical support probably reflects the fact that it is not required as a precondition for registration.

Repellents can be chemical, visual, acoustic, or some combination of these characteristics (Mason 1989). For chemical repellents, sensory irritation (Norman et al. 1992), semiochemical mimicry (Lindgren et al. 1997), or gastrointestinal malaise (El Hani et al. 1998) underlie effectiveness. For visual and acoustic repellents, startle responding (i.e., neophobia) or the avoidance of sign stimuli (e.g., avoidance of eyespots) underlie avoidance. Each of these repellent types and their modes of action are discussed in greater detail below.

CATEGORIES OF REPELLENTS AND MECHANISMS OF EFFECT

Chemical Repellents

There are several effective chemical repellents for herbivores. This is not true for carnivores, although capsaicin-containing products (e.g., bear sprays) do cause irritation, and might cause avoidance under some circumstances. For omnivores, the patent literature suggests a variety of candidate repellents (Werner et al. 1998), albeit with little empirical support. Compounds that may repel dogs (and other canids) include cinnamaldehyde and beta-phenylacrolein (Haase, U.S. Patent No. 4,169,898), methyl nonyl ketone (Haase, U.S. Patent No. 4,555,015), allyl isothiocyanate (Downing, U.S. Patent No. 4,440,783), limonene and alpha-terpinyl methyl ether (Katz and Withycombe, U.S. Patent No. 4,735,803), various carboxylated hydrophilic acrylic copolymers (DeLong, U.S. Patent No. 4,169,902), gamma-n-alkyl-gamma-butyrolactone and gamma-n-alkyl-gamma-valerolactone (Meuly, U.S. Patent No. 3,923,997), various steroids (Hansen et al., U.S. Patent Nos. 4,534,976; 4,657,759; 4,668,455), red pepper (Loucas, U.S. Patent No. 5,368,866), quinine (Loucas, U.S. Patent No. 5,368,866), and pulegone (Mason, U.S. Patent Application No. 351,841).

Chemical repellents are most effective when they are applied directly to foods with the aim of reducing consumption. There is almost no evidence that they cause animals to abandon areas, except occasionally when highly palatable alternative foods are readily available at locations distant from the treated site (Milunas et al. 1994). When alternative foods are scarce or not especially palatable, animals typically return to treated areas and often resume feeding on treated vegetation (El Hani and Conover 1998).

Sensory irritants are nearly always more effective deterrents to depredation than semiochemicals or substances that cause malaise. Avoidance is immediate, no learning is required to sustain the aversion, and adaptation is minimal. A plausible explanation for the strength of responding is that irritants are chemically similar to the endogenous substances released when tissue is damaged (Clark 1998a). Examples of mammalian irritants include capsaicin, the "hot" principle in Capsicum peppers and the active ingredient in "hot sauces," allyl isothiocyanate, the active principle in mustard and the principle active ingredient in tear gas, ammonia, carbon dioxide, and formaldehyde (Mason and Otis 1990).

Irritants are globally effective within taxonomic groups (i.e., irritants that affect coyotes will affect mice). Between taxa, however, there are marked differences in sensitivity and/or perception (Norman et al. 1992). Substances that irritate mammals rarely affect birds. Capsaicin is universally repellent to mammals at concentrations between 10 to 100 ppm; birds are indifferent to capsaicin concentrations >20,000 ppm (Szolcsanyi et al. 1986). On the other hand, methyl anthranilate repels birds at concentrations well below those that are offensive to most mammals (Mason et al. 1991). One practical implication of the difference between taxa is that mammalian repellents that incorporate irritants as active ingredients are unlikely to repel birds. Conversely, the lack of differences within taxa implies that mammalian irritants are as likely to affect humans as they are the targeted pests, perhaps limiting their utility in some situation.

Although irritants may have odors or tastes, olfaction and gustation do not contribute substantially to repellency (Bryant 1997). Tastes, per se, are rarely (if ever) effective repellents. Bitter substances like sucrose octaacetate or denatonium benzoate are undeniably repulsive to humans, but there are few data consistent with the notion that they are aversive to other animals. Herbivores, in particular, are insensitive to these compounds (Nolte et al. 1994). There is no evidence that deer or rabbits are repelled by bitterness, even when these tastes cues are absorbed into plants (Andelt et al. 1991). Products that claim to act via noxious taste cues and purport to repel herbivores (e.g., deer, rabbits, elk) should be treated with skepticism.

Semiochemical odors (e.g., predator urines) and odors that result from protein degradation (e.g., blood meals, rotted egg formulations) will repel herbivores. Avoidance is mediated by sulfur compounds and volatile fatty acids (Lewison et al. 1995; Mason et al. 1997). Sulfur odors may be repellent because they signal the presence of carnivores (Nolte et al. 1994). Alternatively or in addition, sulfur may be aversive because it is a signal for toxicants; plants that bioaccumulate selenium also bioaccumulate sulfur (Mason 1997). Foods with sulfurous odors may "smell toxic" to herbivores. There is no evidence that the semiochemicals present in urine or glandular products are repellent to carnivores or omnivores. Avoidance (or approach) of these substances is predictable from the feeding guild of the animal in question (Mason 1993). Predator urines are aversive to herbivorous fish (Mason 1993), and the odor of rotted cabbages is repellent to grazing snow geese (Mason and Clark 1996a). Despite anecdotes to the contrary, there is little evidence that semiochemicals from one carnivore are repellent to another; for example, foxes are not repelled by coyote urine.

Unlike irritants, there is some evidence that semiochemicals may cause animals to leave areas (Milunas et al. 1994). The extent to which this occurs may depend on the size of treated areas (smaller areas are more likely to be avoided), the number of animals to be repelled (small numbers of animals are more easily repelled), and the palatability of treated foods (unpalatable foods are easier to protect). Unless semiochemical repellents are periodically reinforced with other cues that "validate" the signal quality of the semiochemical, avoidance is likely to be short-lived (Nolte et al. 1993).

Chemical repellency also can be mediated by gastrointestinal malaise (i.e., conditioned taste avoidance). Here, animals learn to avoid arbitrary flavors paired with sickness. Conditioned taste aversions have been tested as a strategy to limit coyote predation on sheep (Conover and Kessler 1994), raccoon predation on eggs (Nicolaus 1987), bird depredation on grain or fruits (Avery 1989; Stone et al. 1974), and in many other contexts (Conover 1998). Success depends on the degree of resemblance between treated and untreated items (Morell and Turner 1970).

Conditioning as a strategy depends on taste (Garcia and Hankins 1978). Mammals do not show strong food avoidance learning when odors or visual cues are used as conditioned stimuli (Reidinger and Mason 1983). Typically, avoidance of cues other than taste depends on the association of those cues with tastes.

Visual Repellents

Visual repellents (eyespots, predator effigies, mylar) are designed to affect birds, although some visual strategies may affect mammals. Birds are "more visual" than mammals insofar as they possess color vision, and the ability to see ultraviolet light (Hunt et al. 1997; Kreithen and Eisner 1978; Parrish et al. 1981). Mammals are often color blind or, if not, only sensitive to blue and green light (400 to 500 nanometers; Neitz and Jacobs 1989). Mammals generally cannot detect the aposematic colors (reds, yellows) that are used to advertised unpalatability and provoke avoidance by birds. Although explanations for insensitivity are few, color blindness may represent an adaptation rather than a weakness. Color blind humans are more able to see through camoflague (Sachs 1995).

Strobe lights may frighten coyotes and other predators (Linhart 1984; Linhart et al. 1984) and disrupt predation on sheep. However, maintanence of avoidance responding requires that devices are used sparingly, moved frequently, and combined with other deterrents (e.g., guard animals, shooting). Stobe lights are not aversive to deer (Dolbeer unpubl. commun.). Other visual strategies (e.g., mylar, scarecrows) may have limited utility, but effects appear to be short-lived. For some mammals (e.g., coyotes), avoidance is influenced by the size and location of the visual deterrent. Small strange objects (e.g., M-44s protruding from the soil) attract coyotes (Roughton and Sweeny 1982), while larger objects (16 cm x 16 cm x 16 cm wooden blocks) are avoided (Windberg 1997). Coyotes are more curious in unfamiliar areas of their home range, but tend to avoid new objects in areas that are well-known (Harris 1983). Unlike chemical repellents, neither the safety nor the efficacy of visual repellent strategies is regulated. Manufacturers' claims about products are often anecdotal.

Acoustic Repellents

Sonic devices include distress calls, pyrotechnics (e.g., live ammunition, shell crackers, firecrackers), propane exploders, and sirens (Hygnstrom et al. 1994). While these strategies are most often used against birds, they have been used to deter mammals (e.g., Bomford and O'Brien 1990; Sprock et al. 1967). At least some of these devices may have utility if use is coupled with other deterrent methods (e.g., hunting, guard dogs; Pfeifer and Goos 1982). However, mammals are at least as likely as birds to adapt to sonic devices.

There is little data that mammals are repelled by ultrasonic devices. In fact, there is almost no evidence that any animal (vertebrate or invertebrate) avoids ultrasonic cues for more than short periods of time (Shumake 1998). So-called "deer whistles," rodent ultrasound systems, and the experimental systems being employed to repel larger mammals have little demonstrated utility. Claims regarding the usefulness of these devices are essentially data-free and at best wildly speculative. Neither the safety nor the efficacy of acoustic repellent systems is actively regulated (Shumake 1998).

Electric Shock

Electric fences can deter deer (Caslick and Decker 1979; Craven 1983; McAninch and Winchcombe 1981) and coyotes (Linhart et al. 1981; Wade 1982) from entering areas. Electric collars can be used to stop predation events (Linhart et al. 1976; Phillips et al. pers. comm.). The utility of the former can be enhanced by attractants (e.g., peanut butter on foil twisted onto the fence wire) that focus animals' attention on the fence (Jordan and Richmond 1992). Principle disadvantages are the high initial cost of installing and maintaining fences.

Shock collars may be especially useful (and perhaps only practical) with "high value" animals (e.g., grey wolves, grizzly bears). Implementation, use, and maintainence are expensive, and a disadvantage is that shock must be delivered precisely. Merely shocking a predator in the presence of livestock will not reliably produce avoidance; shock must be delivered during the predation event, preferably at the moment when contact is made with prey.

ECONOMIC CONSTRAINTS AND POSSIBILITIES FOR DEVELOPMENT

The number of chemical repellents available for vertebrate pest control has diminished in the past decade, despite increasing public interest (Clark 1998b). Simultaneously, the number and variety of visual and acoustic devices has increased. These changes undoubtably reflect the relative costs of new product development and commercialization. On the one hand, visual and acoustic repellents can be brought to market without oversight from regulatory agencies. Commercialization of chemical repellents, on the other hand, is closely monitored by federal and state environmental agencies. Development of methyl anthranilate as the only new bird repellent in the last 25 years took nearly a decade, and cost the manufacturer several million dollars (P. Vogt, pers. comm.). Methyl anthranilate is an approved (GRAS-listed) human and animal food additive (grape-flavoring) and has been so for decades.

Putting aside the issue of cost, attempts should be made to test new products as they become available (to assure that manufacturers' claims are justified). At present, there are few or no data to support claims of efficacy for the majority of commercially available repellents. One result is that strategies are being employed to the probable detriment of homeowners, agricultural interests, and (even) fish and game agencies. For example, ultrasound is being used to deter predation on endangered species in California despite any evidence that the strategy will work.

Wildlife managers need to become more seriously involved in the scientific evaluation of non-lethal methods. Agricultural and wildlife educators need to actively publicize research results so that the public can make informed choices among products. Efforts to develop new repellents might focus on natural products (Reichardt 1998) because environmental protection agencies are moving to expedite the registration of these products (Mason and Linz 1997). Efforts might also focus on broadening the potential applications for known effective substances. For example, products that include rotted egg as an active ingredient are repellent to deer (Lewison et al. 1993). The available evidence suggests that repellency is a consequence of sulfur odors and volatile fatty acids. Because herbivores (regardless of taxonomic class, genus, or species) generally avoid sulfurous odors, it follows that products that include rotted egg as an active ingredient may be broadly repellent to herbivores. A recent study suggests that Deer Away Big Game Repellent is as repellent to eastern cottontail rabbits as it is to white-tailed deer (Mason et al. unpubl. mans.)

Repellents are best considered a part of integrated strategies of pest management (IPM). Thus, chemical repellents are more effective when combined with visual cues (Avery 1998; Mason and Clark 1996b), and propane exploders are more effective when used with guard dogs (Pfeifer and Goos 1982). Non-lethal strategies also may be more effective when reinforced with lethal control. Acoustic repellents, for example, may be more effective when backed up by occasional shooting. Overall, integrating lethal and non-lethal control strategies remains a fertile topic for research. Efforts should be made to educate the public about when and where repellents can be used.

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REVIEW OF BIRD REPELLENTS

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ABSTRACT: Despite a general perception that there is an abundance of nonlethal control technologies, the fact remains that there are fewer registered products and active ingredients for repellents in the U.S. than there were 10 and 20 years ago. This review discusses the technical issues relating to the discovery, formulation, and delivery of chemical repellents, and suggests future avenues of research that would improve our ability to develop effective chemical repellents.

KEY WORDS: bird control, repellent, nonlethal control agents

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INTRODUCTION

Previous reviews have given detailed consideration to the overall process by which repellents are developed, registered, and commercialized Mason and Clark (1992, 1997). In this review the regulatory and commercial status of nonlethal and lethal chemical control agents for birds is summarized. In addition, some of the emerging areas of research affecting the development of effective formulations are reviewed.

In 1988, the Federal Fungicide, Insecticide and Rodenticide Act (FIFRA) was revised by the U.S. Environmental Protection Agency (Fagerstone 1998, this volume). The revision of FIFRA called for more data to evaluate the environmental impact of chemical control agents, and its implementation has profoundly affected the availability of control agents and products. Prior to the revision, the number of active ingredients remained stable from 1978 to 1988. After the amendment, the number of registered lethal control agents decreased 40%, and the number of registered nonlethal control agents decreased by 30% (Table 1). The relative availability of nonlethal active ingredients has decreased by 6% relative to lethal agents over that same period. Similarly, the number of products for lethal bird control has decreased by 66% over the past 20 years. Nonlethal products for bird control have decreased by 41% over the same period. Despite a general perception that there is an abundance of nonlethal control technologies, the fact remains that there are fewer such products and active ingredients than there were 20, and even 10 years ago (Figure 1, Table 2, cf. Schafer 1979; Eschen and Schafer 1986).

Table 1. Summary of EPA registered bird control agents.

	1978		1988		1998	
	No.	%	No.	%	No.	%
Product Labels						
Lethal	35	52	32	49	12	40
Nonlethal	32	48	33	51	18	60
Active Ingredients						
Lethal	5	33	5	33	3	38
Nonlethal	10	67	10	67	5	62

SUMMARY OF ACTIVE INGREDIENTS AND THEIR MODE OF ACTION

Lethal Control Agents

The objective of lethal control agents is to eliminate local populations of birds. Fenthion was originally developed as an organophosphate insecticide and acaricide, but because of its potent irreversible inhibition of acetylcholinesterase it found some utility as a lethal control agent for birds as a dermally delivered (roost) poison (Pope and Ward 1972). Compound DRC-1339 is an avian specific toxicant affecting the renal function of birds (DeCino et al. 1966; Westberg 1974). 1,4-aminopyradine is a toxicant that produces effects similar to central nervous system stimulants (Schafer et al. 1973). Birds ingesting this material die violently, albeit quickly. The repellent effect occurs via observational avoidance learning by nearby conspecifics (Besser 1976).

Table 2. Federally registered chemical control agents for birds.

EPA #	Active Agent	CAS	Product	Company
66330-19	Lindane, captan	58-89-9; 133-06-2	Isotox Seed Treater	Tomen Agro Inc.
58035-13	methyl anthranilate	134-20-3	ReJeX-iT AG-145	R.J. Advantage, Inc.
58035-9	methyl anthranilate	134-20-3	ReJeX-iT AG-36	R.J. Advantage, Inc.
58035-8	methyl anthranilate	134-20-3	ReJeX-iT MA	R.J. Advantage, Inc.
58035-7	methyl anthranilate	134-20-3	ReJeX-iT TP-40	R.J. Advantage, Inc.
58035-6	methyl anthranilate	134-20-3	ReJeX-iT AP-50	R.J. Advantage, Inc.
66550-1	methyl anthranilate	134-20-3	Bird Shield Bird Repellent Concentrate	Dolphin Trust
58630-2	Naphthalene	1146-65-2	Dr. T's Rabbit, Squirrel, Bat and Bird Repellent	Dr. T's Nature Products, Inc.
876-437	Polybutene	9003-29-6; 9003-28-5	Roost No More Repels Nuisance Birds	Velsicol Chemical Corp.
1621-17	Polybutene	9003-29-6; 9003-28-5	Tanglefoot Bird Repellent	Tanglefoot Co.
1621-16	Polybutene	9003-29-6; 9003-28-5	Tanglefoot Bird Repellent	Tanglefoot Co.
8254-4	Polybutene	9003-29-6; 9003-28-5	4 The Birds" Transparent Bird Repellent	Bird Control International Corp.
8254-3	Polybutene	9003-29-6; 9003-28-5	4 The Birds" Transparent Bird Repellent	Bird Control International Corp.
8254-1	Polybutene	9003-29-6; 9003-28-5	4 The Birds" Transparent Bird Repellent	Bird Control International Corp.
9731-1	Polybutene	9003-29-6; 9003-28-5	Preferred Brand" Bird and Squirrel Repellent	Inter-State Oil Co., Inc.
55943-1	Polybutene	9003-29-6; 9003-28-5	Hot Foot Bird Repellent	Hot Foot America
876-436	Polybutene, Aliphatic petroleum hydrocarbons	9003-29-6; 9003-28-5	Roost No More Bired Repellent	Velsicol Chemical Corp.
876-435	Polyisobutylene	9003-29-6; 9003-28-5	Roost No More Bird Repellent Liquid	Velsicol Chemical Corp.
34704-665	Thiram	137-26-8	Thiram 42% Dyed Flowable seed Protectant	Platte Chemical Co., Inc.
34704-664	Thiram	137-26-8	Thiram 42% Dyed Flowable seed Protectant	Platte Chemical Co., Inc.
45735-2	Thymol, denatonium saccaride	89-83-8, 90823-38-4	RO-PEL Animal, rodent and Bird Repellent	Burlington Scientific Corp.
7579-2	Fenthion	55-38-9	Rid-a-Perch 1100 Solution	Rid-a-Bird Inc.
11649-12	4-AMINOPYRADINE	504-24-5	Avitrol FC Corn Chops	Avitrol Corp.
11649-10	4-AMINOPYRADINE	504-24-5	Avitrol Concentrate	Avitrol Corp.
11649-8	4-AMINOPYRADINE	504-24-5	Avitrol Double Strength Whole Corn	Avitrol Corp.
11649-7	4-AMINOPYRADINE	504-24-5	Avitrol whole Corn	Avitrol Corp.
11649-6	4-AMINOPYRADINE	504-24-5	Avitrol Corn Chops	Avitrol Corp.
11649-5	4-AMINOPYRADINE	504-24-5	Avirtol Double Strength Corn Chops	Avitrol Corp.
11649-4	4-AMINOPYRADINE	504-24-5	Avitrol Mixed Grains	Avitrol Corp.
56228-30	3-CHLORO-P-TOLUIDINE HYDROCHLORIDE	7745-89-3	Compound DRC-1339 Concentrate-Staging Areas	USDA-APHIS
56228-29	3-CHLORO-P-TOLUIDINE HYDROCHLORIDE	7745-89-3	Compound DRC-1339 98% Concentrate-Livestock & Fodder Depredations	USDA-APHIS
56228-28	3-CHLORO-P-TOLUIDINE HYDROCHLORIDE	7745-89-3	Compound DRC-1339 98% Concentrate-Pigeons	USDA-APHIS
56228-10	3-CHLORO-P-TOLUIDINE HYDROCHLORIDE	7745-89-3	Compound DRC-1339 Starling posion 75% Concentrate	USDA-APHIS

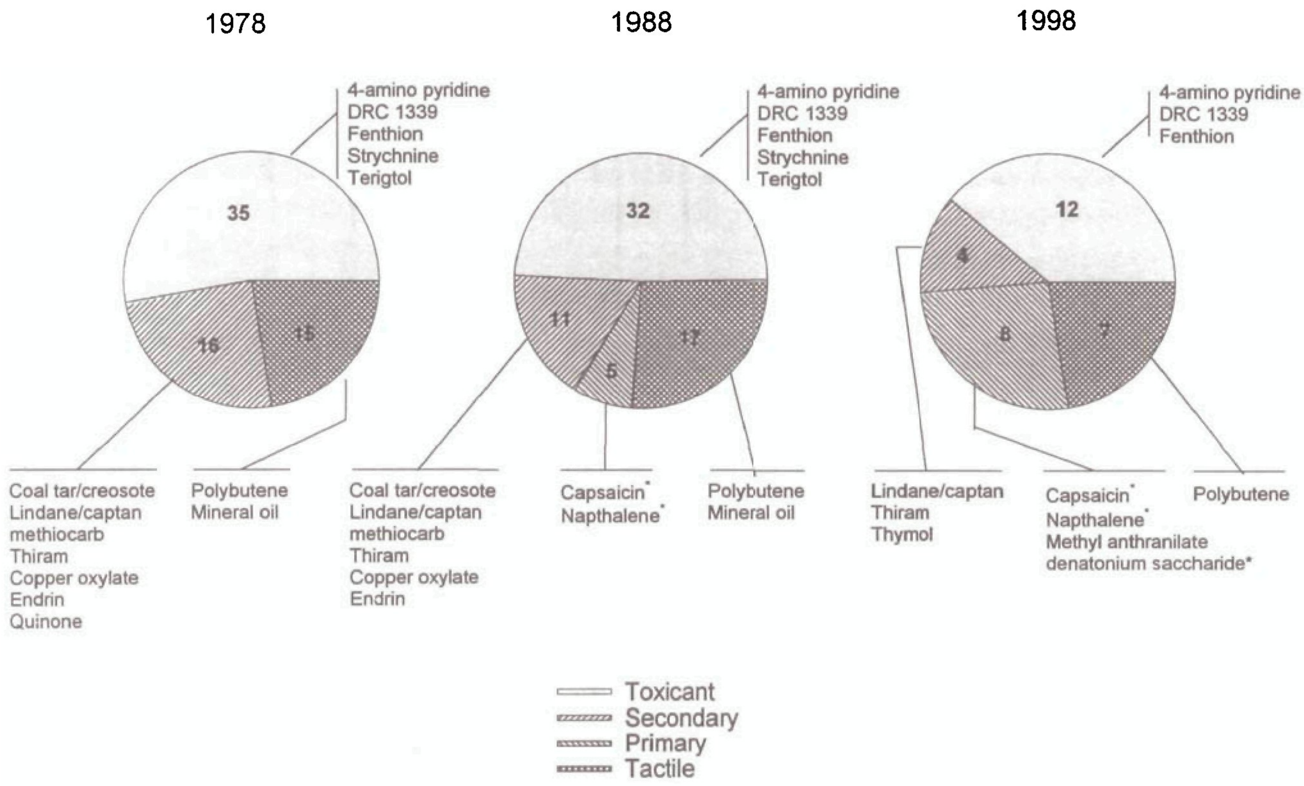

Figure 1. The breakdown of the proportion of U.S. Environmental Protection Agency registered labels by repellent category for the past three decades. The numerical insets within each pie chart reflect the actual number of registered products available at the end of each decade. The registered active ingredients for category of repellent is indicated. Ingredients designated with an asterisk do not have independent peer reviewed evidence as being effective bird repellents.

Tactile Repellents

A variety of registered labels contain compounds that are sticky or oily, and birds avoid these materials based upon their textural and tactile properties. These compounds consist of aliphatic petroleum hydrocarbons, polybutenes, and polyisobutenes, and are applied to surfaces from which birds are to be repelled.

Secondary Repellents

The currently registered secondary bird repellents are derivatives of agricultural products registered for other uses. Methiocarb is a carbamate insecticide whose use was adapted for bird repellency. Cabamates are reversible acetylcholinesterase inhibitors (Hayes 1963; Casarett and Doull 1975; Deichmann and Gerarde 1969). Although Methiocarb was once commonly available for a variety of uses (Dolbeer et al. 1994), there are no currently available commercial products containing this active ingredient. Lindane was initially used as an insecticide; its utility as a bird repellent stems from its stimulatory effect on the central nervous system (Fitzwater 1956; Crosier et al. 1970). Captan and thiram were initially used as fungicides; their utility as bird repellents stems from their action as central nervous system depressants (Fitzwater 1956). Birds apparently detect the physiologic effects of all of these compounds and learn to avoid associated sensory cues (e.g., taste, visual dyes and targets, paired with the toxicants) (Rogers 1974). One product contains the fungicide thymol and a bittering agent, denatonium saccharide. Birds are ordinarily unresponsive to bitter flavors (Mason and Clark 1998). The utility of the bittering agents is their use as conditional stimuli to the toxic effects of unconditional stimuli such as fungicides or insecticides (i.e., thymol). Schafer (1981) provides a review of additional compounds previously registered as secondary bird repellents.

Primary Bird Repellents

Primary bird repellents act as irritants or unpalatable flavor cues that produce a congenital avoidance response by birds (Clark 1998a). There currently is only a single effective registered primary bird repellent, methyl anthranilate. Two other compounds, naphthalene and capsaicin, are registered as bird repellents and can function as primary mammalian repellents. However, there is no evidence to indicate that they, by themselves, are effective against birds (Mason et al. 1991; Clark 1997; Dolbeer et al. 1988). Indeed, over 30 years of basic research has shown that birds lack peripheral receptors for the detection of capsaicin, the active principal in capsicum (reviewed in Clark 1998a).

PRINCIPLES IMPORTANT FOR DEVELOPING EFFECTIVE REPELLENTS

Repellents are tools used by humans to manipulate animal behavior. Thus, the tool can be thought of as a communication device that sends a signal from which the animal extracts a message. Critical to the design of any tool is a careful consideration of form and function, such that when used, its action is efficient in producing the desired effect. For chemical repellents five major factors to consider in the development process can be categorized:

- Mode of Action
- Identification of the Active Ingredient
- Delivery System
- Formulation
- Behavioral and Ecological Context of Application

Mode of Action

Chemical repellents operate along one of three principles: they cause pain, illness, or they scare an animal. Thus, the first myth to dispel about repellents is that they are benign pest management strategies. Repellents are aversive signals that have consequences that an animal presumably is motivated to avoid. Perhaps when considered against lethal control strategies, chemical repellents can be viewed as a less extreme management action, but repellents are by no means benign.

Primary chemical repellents are agents that are avoided upon first exposure because they are olfactorally offensive, distasteful, or cause irritation/pain. For example, predator odors are sometimes avoided by prey, presumably because there is a congenital fear response to being eaten (Sullivan et al. 1988a, b). The avoidance response is directly related to double-bonded sulfur compounds contained in predator urines (Nolte et al. 1994). The presence of sulfurs in the urine is a consequence of protein metabolism and is in direct proportion to the amount of flesh contained in the diet of the predator. Another example of an odor-mediated primary repellent is alarm pheromones. These are chemical signals produced by conspecifics that alert individuals to take evasive action, or in some cases, aggressive defensive action. More often than not these chemical signals are thought to occur primarily in invertebrates (Bell and Carde 1984) and fish (Garcia et al. 1992), but there is evidence for alarm odors in all vertebrate classes (Kavalier et al. 1992; Jones and Roper 1997).

The notion that some chemicals are avoided because they are heuristically unpleasant is untenable. For this to be true, the animal would have to be evaluating the odor on the basis of an aesthetic sense that we have no reason to believe exists. It is more parsimonious to search for a biological basis for the congenital avoidance of odors. Such a less colorful mechanistic approach has utility. Once the underlying basis for avoidance is identified, then the prospect of discovering additional repellents operating along similar principles is improved.

Gustatory-mediated primary chemical repellents are principally bitter or sour compounds. A popular hypothesis is that avoidance of such taste principles is an evolved sensitivity to toxicants and, thereby, is a congenital mechanism to regulate intake of potentially poisonous plant metabolites. While this hypothesis is appealing, the single test of the hypothesis shows that there is no relationship between the palatability threshold for bitter (i.e., alkaloids) and the toxicity of the compounds (Glendening 1994). All of this is not to say that some compounds perceived as bitter or sour cannot be congenitally avoided. However, at the present time there is no *a priori* way of predicting the identity of those compounds. Nonetheless, compounds that are perceived as sour or bitter are potent conditioned stimuli (Riley and Tuck 1985).

Nociceptively mediated primary chemical repellents are compounds that produce irritation and painful sensations (Clark 1998a). For birds, examples of nociceptive repellents are methyl anthranilate, cinnamamide, coniferyl benzoates, and acetophenones (Clark 1997). Chemical irritants form the largest pool of potential primary repellents. Animals have chemoreceptive fibers in their somatosensory and trigeminal systems that respond to chemical neurotransmitters. These transmitters are released when there is tissue damage, stimulating the appropriate nerve fibers and ultimately leading to the perception of irritation or pain. Exogenous chemicals useful as repellents may cause minor tissue damage, thus setting forth the natural defensive mechanism for pain perception in an animal. Alternatively, the exogenous chemical may be a functional analog of the neurotransmitters, thus directly affecting the receptor mechanisms of the nociceptive systems, but without actually causing actual tissue damage. In the latter case, the animal is "fooled" into perceiving tissue damage when, in fact, there is none. While animals may experience physiological sensory adaptation to irritants if they are applied continuously, animals do not adapt or habituate to nociceptive primary repellents when they are applied in an ecological context.

Secondary repellents are agents that cause illness, or an otherwise unpleasant experience, and promote learned avoidance of associated sensory cues. For birds, examples of secondary repellents are anthraquinone and Methiocarb. The persistence of the learned avoidance response is a function of the magnitude of the unpleasant experience and the salience of the associated cue (Pelchat et al 1983). By salience, the author means the appropriateness of the cue relative to the context for which it is presented. Thus, taste cues have high relevance to an animal rendered ill in the context of feeding. Visual and odor cues can be relevant if they are directly paired with food. Sound would have lower salience in the acquisition and retention of avoidance in a feeding context, as would smells not directly paired with the food.

Primary repellents can function as the unconditional stimulus (the aversive experience) and can be used to condition animals to avoid associated sensory cues. However, because primary repellents have a direct and immediate adverse consequence, animals tend to limit their exposure to the agent. Thus, the magnitude of the unpleasant experience is generally less than would be achieved by the poisoning effect of a typical ingested secondary repellent. Hence, the acquisition and persistence of the avoidance response to the associated sensory cues is generally diminished relative to situations when secondary repellents are used (Clark 1996; Pelchat et al. 1983).

It should be clear from the above discussion that a critical feature in the design of a successful repellent is to obtain an understanding of the mode of action appropriate to the application, and be aware of the mechanism (i.e., the target receptor systems) by which the repellent will be mediated.

As indicated above, a next step in the development of a repellent is to identify the appropriate mediating sensory systems of the target species. Repellents designed to be applied to food to prevent consumption by the target species should be directed to affect sensory systems in the mouth. If the same repellent formulation is applied to a substrate in the hope of preventing the target species from standing on a treated surface, there is little reason to expect any degree of success. Yet, this category error occurs with some frequency. For example, the avian repellent, methyl anthranilate, is incorporated into the commercially available formulated product ReJeX-iT AG-36 intended for application to turf. The grass is potentially a food resource for grazing geese, and when the active ingredient is present, the repellent works reasonably well (i.e., geese reduce their feeding attempts on treated turf) (Cummings et al. 1991). However, the treatment will not prevent the geese from standing on the turf. The chemical's ability to penetrate the foot and access receptors sensitive to MA is nonexistent in this application scenario. Thus, if the reason geese are on a patch of turf is to feed, then there is a reasonable expectation of success for the repellent. If the geese are on a patch of turf for other reasons (e.g., loafing), then there is little chance that a topical treatment of the turf will repel the geese.

Delivery Systems

Careful consideration must be given to the mediating sensory system because this will influence the type of delivery strategy that will be employed. For example, contact irritants or texturally unpleasant materials should be designed to target the skin. Animals can learn to avoid treated substrates because the unpleasant sensation is closely coupled to position and movement. However, an agent that can be absorbed through the skin and result in illness will probably not be effective as a repellent because their is no clear localizable sensory cue to associate with the illness. The best repellents are those that unambiguously provide a clearly localizable sensory signal with a consequence. Tactile repellents work because the unpleasant sensation is perceived at the point of contact with the repellent. Tactile toxicants that are absorbed without an obvious peripheral sensation at the point of contact, then subsequently produce illness, lack such clear associations. Thus, the consequence (i.e., illness) cannot be clearly associated with any source (i.e., perch). It is conceivable that an area repellency can be formed, but such responses require a great deal of training and the learned avoidance extinguishes rapidly. Thus, such techniques are of limited use to pest managers.

Repellents that are ingested target oral receptors if they are primary repellents, or gastro-intestinal receptors if they are secondary repellents. In the latter case, tastes, visual cues, or smells associated with food are associated cues that animals can readily learn to avoid. The more clearly the associated cue is paired with the process of ingestion, the stronger will be the learned avoidance. Thus, the taste, smell, or appearance of a food object produces a strong learned avoidance. Smells and appearance of objects in proximity to ingested food containing the repellent will require more training for learned avoidance to occur, if at all. Thus, the key to success is not only the ability to locate and associate the conditional cue, but that cue must also be likely to co-occur with food.

Finally, an aerosol delivery might target multiple sensory systems, skin, eye, nose and oral receptors. Such a delivery of repellents will almost always contain irritants. Because the source will invariably be broad, the likely response is to promote undirected escape behavior by the target animal. Thus, of all the strategies, aerosols are the most likely to succeed as areas repellents. The disadvantage of aerosols is that they are of short duration because of rapid atmospheric dispersal. However, beside their direct effect on behavior via irritation, such repellents might be used as reinforcing stimuli to other nonchemical hazing devices, pyrotechnics, and sound where habituation is a problem over long periods of time.

From these examples, one can see how targeting a particular sensory system may relate to the design of the formulation and delivery system, and to the ecological context under which the repellent is applied.

Identification of the Active Ingredient

At the beginning of this paper, the author reviewed how many registered repellents were derived from existing pesticides owing to their general physiological effects (see also Schafer 1981). Such derivative repellents are falling from regulatory favor because of there broad toxicological effects on vertebrates (Hushon 1997; Mason and Clark 1997).

Other sources of repellents include screening natural products (Greig-Smith et al. 1983; Crocker and Perry 1990; Reichardt 1997) and food and flavor ingredients (Mason and Clark 1992). However, there is no guarantee that such compounds are intrinsically safer from an environmental or toxicological perspective (Secoy and Smith 1983). But there is a general perception that the likelihood of finding environmentally safe repellents from such compounds is higher (Liss 1997).

A predictive model for identification of primary bird repellents would be of great utility in minimizing research and development costs for new repellents. Considerations of primary and toxicity effects, formulation considerations, registration hurdles and production and market considerations all can eliminate candidate repellents from the development process. Reliance on serendipitous discovery of repellents only reduces the likelihood that nonlethal control methods will be successfully developed. The pharmacophore approach to rational repellent design so successfully used for product identification in the pharmaceutical and food industries can also be used in developing repellents. The fundamental premise behind molecular structure-activity models is to numerically characterize chemicals and relate the descriptor variables to a relevant biological response. Availability of software packages to characterize the semi-empirical quantum mechanical, topological, physicochemical attributes of molecules has greatly facilitated this approach (Lipkowitz and Boyd 1991). The QSAR approach to simple aromatic compounds has been successfully employed to develop a robust statistical model predicting primary bird repellents (Clark and Shah 1991, 1994; Clark et al. 1991; Shah et al. 1991; Clark and Aronov 1998). However, more work is needed to extend the predictive power of the model to other classes of compounds (e.g., terpenoids, alkaloids).

Current methods for identification of active ingredients rely on behavioral testing. When large numbers of compounds are screened, this can be an expensive animal intensive effort. Recent advances in cell culture technology allow for the rapid screening of large numbers of compounds (Banker and Goslin 1991). In particular, trigeminal cultures for several species of mammals and birds have now been developed. These cultures will allow the bioactivity level to be evaluated for large numbers of candidate primary repellents (Bryant, Clark and Mason, unpublished).

Formulation Considerations

Once the active ingredient is settled upon, incorporating it into a formulation appropriate for a specific delivery mode is critical. Chemical repellents are rarely delivered in raw or reagent form. In the simplest case they are diluted by water and applied according to label instructions. However, uniformity of application, adhesion to the treated substrate and uniform coverage can be enhanced by using agricultural adjuvants. These adjuvants may be classified as: 1) spreaders, stickers, buffers, foliar nutrients; 2) penetrants, crop oil concentrates, extenders; and 3) drift control agents, deposition agents, or retention agents (Harvey 1992). Spreader/ stickers control the deposition of the active agent on the treated substrate and control the life of the active agent. Wetting agents and spreaders decrease the surface adhesion of the applied materials, thereby allowing increased uniform coverage. Sticker/extending agents control the life of the active agent by encapsulating the agent and slowing down environmental degradation (e.g., biodeterioation and weathering losses). However, one must always bear in mind compatibility constraints with the carriers and active ingredients. Chemical interactions may occur that effectively render the active agent unavailable to the receptor systems of the target species. Some of these interactions may be predictable, and with consultation with a formulation chemist or manufacturer of the adjuvants, such problems may be avoided prior to field trials or operations. However, most likely trial and error matching adjuvants and repellent formulations will be necessary, having run these trials in small pilot studies.

There may be circumstances where mixtures of active agents may be desirable. The relationship between a chemical's concentration and its repellent effect has been described for a wide range of compounds (Clark 1997). These concentration-response studies are useful for their simplicity and straightforward interpretation in setting standards for formulation development. However, to attain practical validity, the interaction of agents in mixture must also be studied. This entails studies of interaction of multiple active agents with each other, and with interactions of agents with the other ingredients in formulations.

Formulations composed of multiple active agents may exert an additive effect. That is to say, the repellency observed is simply the average of the expected concentration-specific response of the component ingredients. Thus, studies based on single agent concentration response profiles theoretically are useful in making predictions about the activity level of the mixture. Unfortunately, this is rarely the case. In other sensory systems (i.e., olfaction and gustation), an animal's responsiveness to a mixture is often predicted based upon its reaction to the most stimulatory component in the mixture. It is as if the animal screens out the sensory information of the mixture and attends to a single sensory input of the strongest stimulus. However, there also are numerous examples where animals perceive mixtures not on the basis of their individual components, but as an unique quality (i.e., an integration of the components) where the concentration-response to the mixture is not predictable based upon a knowledge of the component's concentration-response relationships. Under these circumstances the perceived intensity of the mixture may be less than the sum of its parts (antagonism of components), or greater than the sum of its parts (synergism). Trying to identify principles that allow investigators to predict precisely what type of interaction among agents may occur is an area of considerable interest in chemosensory biology. Recent studies from the author's laboratory have begun to address these issues for primary repellents (Clark 1997, 1998b; Clark and Mason 1998), but this remains a largely unexplored area of research from an applied wildlife management perspective.

The stability of active agents in formulation can be affected by several other factors such as carriers, stabilizers, solvents, binders, biocides and antioxidants, just to name a few. Microbial degradation of early formulations of MA were serious considerations in the developmental process (Clark et al. 1993; Aronov and Clark 1996). Even today, the success of MA containing products is directly related to the life expectancy of the active ingredient, and this varies according to the environmental conditions regulating weathering and microbial attack (Clark et al. 1998; Mason and Clark 1995, 1996; Dorr et al. 1998). Such considerations are critical in evaluating the effectiveness of repellent formulations. When a formulation fails to meet performance expectations, the first consideration should be an evaluation for the presence of the active agent. Regrettably the early literature on product performance in the field is rampant with studies that concluded inappropriately that the active agent was not a good repellent, rather than the possibility that the application strategy and formulation were not appropriate for the environmental and ecological circumstance under study. In effect, many studies "threw the baby out with the bath water."

Behavioral and Ecological Context of Application

The myriads of social and environmental factors affecting the efficacy of repellents is beyond the scope of this review. Nonetheless, they are critical to the final successful use of repellents (Clark 1998a).

In summary, the development of a successful repellent formulation is seen more than simply discovering a single "new" compound. A basic understanding of the mediating sensory system of the repellent is needed to best develop a formulation and delivery system. Moreover, given the technical, commercial, and regulatory constraints, reliance on a single candidate repellent at the outset is a strategy unlikely to lead to a viable product. Thus, methods to generate families of candidate repellents and rapidly validate the bioactivity of the repellents are needed. These processes are critical for the development of new wildlife management tools because the number of nonlethal methods and products has actually decreased over the past 10 years.

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DEVELOPMENT OF A NEW BIRD REPELLENT, FLIGHT CONTROL

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ABSTRACT: In August 1995 the development of a new bird repellent, Flight Control containing anthraquinone, was initiated. A series of laboratory formulation testing, cage and pen studies were conducted. The anthraquinone discrimination threshold (concentration at which birds could detect the test material) for starlings (*Sturnus vulgaris*) was 151 ppm in treated feeds. The model revealed that to achieve 90% repellencey with Flight Control, the treated material should receive 1,131 ppm of anthraquinone. Bird feed containing pesticide granules treated with 1% anthraquinone and control feed in a lab choice study, resulted in zero mortality in quail chicks (*Colinus virginianus*). Pen studies with American robins (*Turdus migratorius*) demonstrated Flight Control repelled the species when holly berries were treated with 500 ppm anthraquinone. Pen studies in Louisiana using Flight Control-treated rice seeds generated efficacy in excess of 90% to cowbirds (*Molothrus ater*) and red-winged blackbirds (*Agelaius phaeniceus*).

KEY WORDS: Flight Control, anthraquinone, starling, red-winged blackbird, robin, choice test, repellency, discrimination threshold

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INTRODUCTION

Genesis Laboratories, Inc. was contracted by Environmental Biocontrol International (EBI) of Wilmington, Delaware, in August 1995 to assist in the development of a new bird repellent—Flight Control, containing anthraquinone. As a result, a research and development plan was drafted to complete various laboratory, pen, and field studies to identify the optimum formulation of Flight Control to achieve maximum efficacy.

The objective of this project was to examine for efficacy of Flight Control when used to repel key target bird species. The potential primary hazard reduction of granular pesticides treated with Flight Control was investigated using young and adult birds.

MATERIALS AND METHODS

Flight Control

The Flight Control test material was a liquid formulation containing 50% anthraquinone (CAS No. 84-65-1; SHA 122701; EINECS 201-549-0). The repellent was a tan-colored liquid packaged in plastic bottles by EBI. This study was initiated on August 28, 1995 and research is continuing to date.

Test Birds

Scientific collecting permits were obtained for the various species used in this study from the U.S. Fish & Wildlife Service and the Louisiana Department of Wildlife & Fisheries, Environmental Branch. Birds were collected using mist nets and modified Australian crow traps. The species utilized included the European starling (*Sturnus vulgaris*), American robin (*Turdus migratorius*), cowbird (*Molothrus ater*), red-winged blackbird (*Agelaius phaeniceus*), and Northern bobwhite quail (*Colinus virginianus*). Starlings were collected from Larimer and Weld counties, Colorado. Birds were captured near cattle or sheep feedlots, in sugarcane fields, along tree lines, and in rice fields. All birds used in the testing, with the exception of bobwhite quail, were obtained from wild populations. Bobwhite were obtained from Barrett's Quail Farm, Houston, Texas. Quail chicks were hatched from captive bobwhite utilizing incubators at Genesis Laboratories.

Housing and Maintenance of the Test Birds

Cage studies were conducted at the Genesis facility near Wellington, Colorado. Racks on rollers contained nine individual cages (63 x 63 x 45 cm), with stainless steel dividers separating birds. Only one bird per cage was used during the research in order to obtain information on individual variation in food consumption. Test rooms were equipped with automatic timers to maintain light at 12 hours light/dark. A central heating system maintained test rooms between 20-22°C and the relative humidity between 35-55%. Test rooms were isolated and only one species per room was allowed. Noise was kept to a minimum as not to disturb the captive birds.

Captive birds were fed a maintenance ration consisting of 75% Ranchway Feed Game Bird Grower, 20% whole grain millet or wheat, and 5% oyster shell grit. If birds tested in choice studies were to use millet as a carrier, millet was included in the maintenance ration.

Laboratory Choice Tests

Starlings were used as the main laboratory test birds since the species is ubiquitous, a common problem to farming operations, and very abundant in the U.S. (approximately 600 million in the continental mainland). Wild birds were allowed to condition to the test facility and conditions for approximately one week or more before assigned to a study. Birds were presented treated grain and control (untreated grain) in separately marked cups in choice tests. The position of the cups was reversed daily. In most studies, the exposure period normally lasted four days. Consumption was recorded daily (nearest 0.1 g).

Test groups per dose level consisted of 9 to 10 starlings. All birds were adults or sub-adults (young of the year which were adult sizes but have not fully come into adult plumage). Similar studies were repeated on red-winged blackbirds and robins in Louisiana.

A study was conducted to determine the discrimination threshold, or the concentration at which Flight Control might have repellency action. Methods described by Bennet (1989) and Bennet and Schafer (1989) were followed.

Laboratory choice tests using 10-day-old bobwhite quail chicks were conducted to determine at what dietary level repellency induced by Flight Control might be achieved to reduce bird consumption of products in the field, such as granular herbicides or insecticides. Birds were housed in brooders, where the temperature was maintained at approximately 38°C. Tests were from 3 to 5 days exposure with food trays reversed daily. In some of the studies, it was possible to calculate the discrimination threshold.

A laboratory study was completed to assess whether or not the repellency action of Flight Control was related to taste or odor. A feeding container was devised using a modified base for a standard 0.5 L bird waterer. The metal water receptacle contained a center portion that screwed onto water jars. The outer portion of the lid, contained the area where water is available to birds. Flight Control treated millet (1,000 ppm) was placed in the outer portion of the lid and covered with wire mesh. Untreated millet was provided in the center of the lid and served as the basal diet for the individually housed birds. Feed consumption was recorded after two consecutive days, with the position of the cups reversed each day. The hypothesis tested was thus: if odor is the major role involved in repellency, then feed consumption in the feed trays with treated Flight Control would be significantly less than the cup with the untreated seed.

Studies were conducted to determine if granular pesticides treated with Flight Control were avoided by 10 to 15 day old bobwhite quail chicks. Birds were offered treated trays with insecticides and control food trays. Mortality was recorded over 5-day exposure and 3-day observation periods.

Pen Studies

Repellency studies on granular products were conducted at the Genesis facility in Colorado, utilizing Northern bobwhite quail adults (groups of 5 to 10) housed in 5 x 10 m outdoor pens. In all pens studies conducted, water and maintenance feed were provided *ad lib.* when birds were not on tests. During studies sufficient food and water were made available to avoid undue stress to birds. Pesticide granules were treated with various concentrations of test material and presented in choice test along with control feeds. Designs included direct treatment of granules and combined feed and granular mixtures treated with the test material. Consumption was recorded daily and mortality monitored.

Pen studies were also conducted in Louisiana using red-winged blackbirds, cowbirds, and American robins to determine the potential repellency on rice, millet, and berries. Six 10 x 3.5 x 3 m and one 10 x 3.5 m pen were constructed in a secluded area amongst sugarcane fields. Food and water were provided *ad lib*. Choice tests were employed in both individually caged birds and pens. Oil field pipe and plastic netting were used to enclose the pens. An opaque cloth was placed over the top one-third of pens to protect birds from unnecessary stress induced by sunlight and rain. Perches were installed at each end of the pens to provide roosting sites and protection against bad weather.

Methods similar to those developed by Avery (1989), Avery and Decker (1991), Avery et al. (1993) and Holler et al. (1982) were used. Within pens, 1 x 1 m raised plots 5 cm above ground level were constructed with wood and filled with dirt. These were positioned equidistant from the perimeters of the pen and a minimum of 1 m apart. The number of plots varied from 4 to 10 depending on the number of birds (2 to 20) placed into the pens (red-winged blackbirds or cowbirds). From 200 to 1,000 rice seeds were placed onto the plot after appropriate preparation. Control plots received soaked rice with no Flight Control. After a 1 to 3 day exposure period, the number of remaining seeds was counted. Birds were conditioned to the pens for a minimum of three days before test material was applied.

In southern Louisiana, rice farmers generally soak rice seed in water and air dry before planting. This is to help the seeds germinate before planting, in hopes that the young plants will become established sooner and bird damage might be less. For studies with sprouting rice, rice was soaked for 24 hours and allowed to air dry before usage. Two types of treatment were used: pre-soak, where the rice was treated with the Flight Control, soaked in water for 24 hours, air dried for 24 hours, then applied to plots. Post-soak treatment involved: soak the rice for 24 hours, air dry for 24 hours, treat with the appropriate amount of Flight Control, air dry for one hour, then applying to the test plots (see Holler et al. 1982).

For studies with grains and berries, the appropriate amount of Flight Control was weighed out and mixed with the carrier in plastic bags for five minutes. The formulated product was then allowed to air dry for about 30 minutes before use. Methods developed by Tobin and DeHaven (1983) were used in establishing these choice tests between treated and control berries or grains.

RESULTS AND DISCUSSION

The initial studies revealed that starlings were able to detect Flight Control at 151 ppm, however, the compound did not have a sufficient repellency effect until a higher dose was used. The discrimination test results are presented in Table 1. To attain 90% repellency using Flight Control against starlings, the treatment concentration would require 1,131 ppm of anthraquinone.

Experiments were conducted with various carriers. Table 2 presents the results of Flight Control in m-pyrol formulation. The results for a 500 ppm treatment during this stage of early product development showed little effects on repelling birds. Other formulations tested using different solvents at 100 ppm showed no significant effects on repellency at lower concentrations of Flight Control (Table 3).

Results of the odor test are presented in Table 4. There was no difference in seed consumption between the treated and control containers. Odor does not play a role in the repellency of Flight Control. Observations from

Table 1. Values for determining the discrimination threshold for Flight Control in starlings.

Group	Nominal Concentration ppm	Log Concentration (X)	Log (Unit/Treatment) (Y)
T-1	0	0.0	0.00
T-2	100	2.0	0.07
T-3	250	2.4	0.22
T-4	500	2.7	0.38
T-5	1000	3.0	0.73

X^{DT} = 2.178
Slope of regression line above X^{DT} = 0.85
Discrimination threshold (antilog X^{DT}) = 151 PPM
95% Confidence limits ($F_{1,3}$ = 10.13):

Table 2. Four-day choice test and a new carrier using adult starling, with nine birds per group. Flight Control-treated millet was compared to untreated millet. Results are in grams.

Groups	Average Untreated	Average Treated	Total Consumption	Percent Untreated	Percent Treated
Control	17.01	19.38	36.39	46.7	53.3
M-pyrol Blank	14.96	9.16	24.12	62.0	38.0
100 ppm	9.58	10.18	19.76	48.5	51.5
300 ppm	12.48	14.01	26.49	47.1	52.9
500 ppm	14.28	11.53	25.81	55.3	44.7

Table 3. Average daily feed consumption of starlings during a three-day discrimination test (choice) with three Flight Control formulations.

Groups	Nominal Concentration (ppm)	Feed Consumption (grams/bird/day)				
		Treated	%	Untreated	%	Total
Control	0	8.3	61	5.2	39	13.5
PCC-942	100	0.6	3	15.7	97	16.3
PCC-943	100	5.7	27	15.2	73	20.9
PCC-944	100	12.1	55	9.8	45	21.9

PCC-942: 1% w/w napthalene. PCC-943: 1% w/w; corn oil. PCC-943: 1% w/w in tap water.

Table 4. Four-day choice test to determine if odor is repellent mode of action for Flight Control using ten (10) adult starlings. Consumption is given in grams.

Day	Average Untreated	Average Treated	Total Consumption	Percent Untreated	Percent Treated
1	7.73	6.54	14.27	54.2	45.8
2	7.20	7.39	14.59	49.3	50.7
3	6.38	8.13	14.51	44.0	56.0
4	11.07	4.57	15.64	70.8	29.2
Total	31.44	25.89	57.33	54.8	45.2

Initial feed amount for all feed pans was 30 grams. Millet was used as the carrier. 2000 ppm anthraquinone formulation was used.

both the laboratory and pen studies revealed that there were no adverse effects on the behavior and health of birds used in Flight Control research.

Table 5 presents the results of a choice test with bobwhite quail chicks presented Flight Control treated and untreated trays of insecticide granules. This study was a choice test to determine the discrimination threshold (DT): the dietary concentration at which northern bobwhite chicks begin to consume a greater proportion of untreated feed than treated feed.

Table 5. Laboratory choice test using bobwhite quail chicks (12 days old) in which Flight Control treated insecticide-treated granules or untreated granules and quail feed were provided over a five-day exposure period.

Treatment Groups	% Mortality
Control (0 ppm)	6/20 = 30
Vehicle Control (4.0 mL solvent)	2/20 = 10
T1 (2,000 ppm)	2/20 = 10
T2 (5,000 ppm)	3/20 = 15
T3 (10,000 ppm)	0/20 = 0

Control = insecticide-treated granules in one tray and quail feed in another; VC = insecticide-treated granules with 1% carrier; Replications I and II were added together for a total of 20 birds in each treatment group.

Cumulative mortality data is presented in Table 6. Deaths during the no choice test occurred on the first day in both treatment groups as a result of the birds consuming lethal quantities of the treated feed. To determine the mortality, two diets were used: 8,000 ppm treated insecticide granules mixed with feed and insecticide granules and feed mix. Two groups of 10 were used for each treatment group, as well as two groups of 10 for the control group. Group T1, insecticide treated, had 16 deaths by the end of the five-day test period and group T2, insecticide-treated, had 14 deaths. Mortality was 80% and 70%, respectively. The toxicity of the granule afforded little time for a learned behavior response, thus inducing high mortality.

The results of the 5-day discrimination threshold test conducted with Flight Control in northern bobwhite chicks showed the discrimination threshold to be 1,180 ppm (Table 7). To determine the discrimination threshold, certain criteria must be met; the vehicle control group must have, basically the same X and Y values and the treatment groups' X and Y values should increase proportionately. The vehicle control group ate considerably more of the raw feed treated with corn oil as opposed to raw feed only (Table 8). The Y values, LOG (untreated/treated), did not increase as the X values, LOG concentration, increased.

To determine the discrimination threshold, eight treatment levels were used; 10 ppm, 25 ppm, 50 ppm, 100 ppm, 200 ppm, 400 ppm, 800 ppm, and 1,600 ppm. At the 800 ppm level, there was a marked change in the feeding habits of the chicks, implying that at this level the Flight Control did repel the birds.

Pen and cage studies conducted in Louisiana during January 1996 revealed the potential for Flight Control for use as a repellent against American Robins and red-winged blackbirds (Table 9). Although the highest concentration tested was only 1,000 ppm, the repellency was 60%, indicating the potential for more effective damage reduction at higher levels.

Subsequent studies during the summer and fall of 1996 demonstrated the efficacy of Flight Control in sprouting rice to repel red-winged blackbirds and brown headed cowbirds. Table 10 presents the data for treatments at different periods, presoak and post-soak treatments. In both cases, Flight Control has shown to be potentially effective in pen situations.

Pen and field observations of bird behavior were made throughout the studies. In no situation were adverse effects or discomfort induced by Flight Control to the birds observed. In feeding on rice seeds, the birds squeezed the grain from the hull then ejected the hull from the mouth and ate only the inner grain. During this feeding activity, which maximized contact with Flight Control, the treated seeds did not affect the bird's behavior or induce pain. Consumption of Flight Control did not affect feeding behavior, in terms of grams of feed per day.

Upon completion of all studies, birds were released near the original point of capture. No test birds died due to exposure to Flight Control. In a separate study, it was found the LD_{50} in northern bobwhite quail to be in excess of 2,000 mg/kg body weight. This was the standard limit test conducted for the U.S. Environmental Protection Agency.

In the laboratory studies involving quail chicks, mortality was induced by other pesticide granules, and not the test substance in question. Results of this research indicate the possibility of using Flight Control as a bird repellent when formulated with toxic granular pesticides.

Table 6. Mortality of northern bobwhite quail chicks during a study using Flight Control corn oil formulation to treat insecticide-treated granules.

Group	Nominal Flight Control (ppm)	Mortality Group Size
VC-R1	0	1/10
VC-R2	0	0/10
Total		1/20
T1-R1	8,000	7/10
T1-R2	8,000	9/10
Total		16/20
T2-R1	8,000	6/10
T2-R2	8,000	8/10
Total		14/20

VC = Raw feed + corn oil
T1 = insecticide-treated granules + 1,000 ppm Flight Control and raw feed + corn oil
T2 = insecticide-treated granules + raw feed + corn oil
R1 and R 2 = replicates

Table 7. Values for determining the discrimination threshold of Flight Control with corn oil carrier in a choice test using northern bobwhite quail chicks.

Group	Nominal Concentration Flight Control (ppm)	Log Concentration (X)	Log (Unt/Trt) (Y)
VC	0	0.000	-0.504
T-1	10	1.000	-0.260
T-2	25	1.398	-0.346
T-3	50	1.699	-0.604
T-4	100	2.000	-0.521
T-5	200	2.301	-0.184
T-6	400	2.602	-0.382
T-7	800	2.903	0.449
T-8	1600	3.204	0.125

X^{DT} = 3.072
Slope of regression line line above X^{DT} = 0.211
Discrimination Threshold (antilog X^{DT}) = 1180 PPM
95% Confidence Limits ($F_{1,7}$ = 5.59)

Table 8. Mortality in one month old northern bobwhite chicks exposed to insecticide granules treated with various concentrations of Flight Control over a five-day test period.

Treatment Group	Total Mortality	Percent Mortality
Control	0/13	0.0
0 ppm	2/26	7.7
2,000 ppm	14/24	58.3
5,000 ppm	17/25	68.0
10,000 ppm	0/26	0.0

All treatment groups received Flight Control + insecticide-treated granules. Control was raw feed.

Table 9. Results of cage and pen studies conducted on birds in Louisiana during January 1996. The carrier (fruit or grain) was treated with Flight Control. Untreated carrier was provided as control food in the choice studies. Birds were caged individually, when more than one was placed into pens.

Flight Control (ppm)	Target Species	Treated	% Repellency
Cage Studies			
50	American Robin	holly berries	53.0
250	American Robin	holly berries	52.4
400	American Robin	holly berries	33.5
500	American Robin	holly berries	51.3
1,000	American Robin	holly berries	60.0
50	red-winged	rice	60.5
500	red-winged	millet	68.9
1,000	red-winged	millet	66.4
Pen Studies			
500	American Robin	holly berries	68.9
1,000	American Robin	holly berries	69.7

Table 10. Results of pen studies conducted in Louisiana using 5,000 ppm Flight Control treated rice when presented to red-winged blackbirds and cowbirds.

Species	Exposure Period	No. Birds	Treatment Type	Seeds Per Pen	Consumption Control	Consumption Treatment	Repellency (Percent)
red-winged	2 days	3	Pre	2,400	753	198	79.2
red-winged	2 days	3	Post	2,400	1,200	701	63.1
red-winged	2 days	3	Pre	2,400	2,160	240	90.0
red-winged	2 days	3	Post	2,400	2,129	271	88.7
cowbirds	2 days	20	Post	10,000	4,892	2,105	69.9
cowbirds	2 days	20	Post	10,000	2,661	1,164	80.0
cowbirds	1 day	10	Pre	10,000	2,459	864	74.0
cowbirds	1 day	10	Pre	10,000	4,590	459	90.1

[1]Treatment type: pre-soaked rice (Flight Control treatment before rice was soaked in water for 24 hours; post-soaked rice (Flight Control treatment after rice soaked for 24 hours and air dried for 24 hours).

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FIELD TRIAL USING FLIGHT CONTROL AS A REPELLENT FOR CANADA GOOSE (*BRANTA CANADENSIS*) CONTROL IN FORT COLLINS, COLORADO

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ABSTRACT: Flight Control, containing anthraquinone, was field tested during 1997 in Colorado as a repellent to keep Canada geese (*Branta canadensis*) off turf. The product was sprayed at a rate of 1.9 kg per ha, using a boom sprayer towed by a golf cart. The reduction in goose numbers on the treatment plot was 95.1% ten days after application. A decline of 64.7% in the number of goose droppings on the area was recorded.

KEY WORDS: anthraquinone, Flight Control, Canada goose, efficacy

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INTRODUCTION

This study was conducted to test the field efficacy of Flight Control, containing anthraquinone, as a repellent for Canada Geese (*Branta canadensis*). The study was conducted in Fort Collins, Colorado at Woodward Governor. The study was conducted from February 20, 1997 to March 21, 1997.

METHODS AND MATERIALS

Study Site

The study was conducted at Woodward Governor, a private corporation located in Fort Collins, Colorado at the intersections of Drake Street and Lemay Avenue. It is a fenced and gated site that is used extensively by Canada geese for feeding, resting, and nesting. The site is well maintained and is comprised of large Kentucky bluegrass (*Poa pratensis*) lawns complemented by several deciduous and coniferous trees and several types of shrubs. Located on the northeast corner of the grounds is a softball field used by employees of Woodward Governor in the spring and summer months. The site is used throughout the year by resident geese and migrating geese. Across Lemay Avenue is a large private pond that adds to the attraction of Woodward Governor as a feeding and resting place for Canada geese by providing additional resting and escape cover.

Goose droppings cover the entire grounds of Woodward Governor including the lawn areas, sidewalks, driveways, and the softball field. Maintenance workers have used scare tactics, including pyrotechnics and harassment, but have had little success at removing the birds or reducing their numbers. Nesting on company grounds has been a main concern for the company due to the increase in aggressiveness and conflicts with geese that are raising young.

Study Plots

In cooperation with the maintenance crew at Woodward Governor, two plots were established on the northern lawn area, adjacent to the softball field. These sites were chosen based on prior observations of geese feeding in the area at the same time every day. Geese were also observed to use the south lawn but, the maintenance crew preferred the north lawn be used. The control plot was established to the east of the softball field and the treatment plot was placed on the west side of the field. Pretreatment counts of the plots yielded little to no data on goose numbers or droppings, but geese were continually observed using the south lawn area in large numbers. Two new plots were then established on the south lawn on February 28, 1997. Two plots measuring 0.4 ha each were established directly adjacent to one another, resulting in a 0.8 acre study site. The plots were 65 meters on each side and were marked with blue flags around the perimeter. To separate the control plot from the treatment plot yellow flags were used as the dividing line. A transect was laid out across the treatment plot diagonally from the northwest corner to the southeast corner. The transect measured 60 meters long and one meter wide. A transect was also placed in the control plot stretching from the northeast corner to the southwest corner, with the same measurements as the treated plot transect. Transects were marked using lime.

Observations

Observations were made from 0800 to 0821 everyday at five minute intervals. Counts were made on the number of geese present in each plot, and the entire area. Notes were made on the activity of the geese to record feeding, resting, and social activities. Five counts were made every five minutes from a distance of approximately 25 meters to avoid disturbing the geese. Counts were made from a vantage point that ensured geese were counted in the appropriate plot, and binoculars were used to confirm all geese were counted. The droppings count was made after the five goose counts were completed. Transects were walked by one or two technicians and fresh droppings were counted. To ensure consistency, all droppings touching the lime boundaries of the transect were counted to be in the transect. Droppings were removed from the transects to avoid counting them in following days.

Treatment Application

The treated plot was sprayed with the test substance at 0700 hours on March 11, 1997. On the preceding day the sprayer was calibrated, but spraying did not occur because of high wind speed and possibility of drift onto the control plot. An additional spraying was performed on March 12, 1997 because the sponsor wished to increase the application rate by 50%. For each application, 947 g of test material was mixed with approximately 45 L of water in a 100 L Snyder Sprayer. The application rate for both days was 1,894 g of anthraquinone per hectare.

The sprayer had an attached boom, with a swath width of approximately 6.5 m, at 50 psi. The sprayer was attached to a golf cart and approximately 11 passes were made to cover the entire treatment plot. Observations of geese were conducted in the same manner post-treatment for seven days.

RESULTS AND DISCUSSION

Data were analyzed to compare the effect of test substance on the number of droppings and the number of geese per plot (Tables 1 and 2). Pre-treatment data were collected on the control plot and the treated plot, and compared to post-treatment data. The mean of the highest number of geese observed on each plot was calculated and the percent change was determined (Table 3). This analysis showed a 95.17% reduction in goose activity on the treated plots which indicated a decreased use of the treated plot by geese after treatment with the test substance (Table 3). The number of geese on the control plot was also analyzed for percent change (Table 3). This analysis showed a 312.18% percent change in activity, indicating there was an increased use of the control plot after the test substance was applied (Table 3).

The number of goose droppings was used as a secondary indicator of efficacy. Pre-treatment and post-treatment numbers were tabulated from both the treated and control plots. The treated plot showed a 64.74% efficacy, which denoted a decrease in use of the treated plot (Table 4). The control plot displayed a 52.40% efficacy signifying an increased use of the control plot after the test substance was applied (Table 4).

Data were analyzed for trends in the number of goose droppings and the number of geese per plot for pre- and post-applications. The number of droppings on the control plot showed a positive trend from pre- and post-treatments, indicating an increased use of the control plot after the test substance was applied (Fig 1). The treated plot showed a negative trend in droppings after application of the test substance. Trends in goose counts showed a positive increase on the control plots and a negative trend on the treated plot (Fig. 2).

Preliminary indications of this study support the efficacy of anthraquinone as a field repellent for Canada geese. Data analysis indicates that anthraquinone is an effective repellent even under varied weather conditions, including snow accumulation. The test substance appeared to repel the geese even after the accumulation of six inches of snow that lingered for three days (Table 1). Observations of geese during the field trial demonstrated their avoidance of the treated plot for several days. Geese were observed to feed freely throughout the Woodward Governor compound and would even feed within 5 to 10 feet of the treated plot, but would not cross onto the plot. This may indicate a learned response and avoidance to the repellent after the initial application.

Observations of geese during the post treatment period did not indicate any adverse effects to individuals or flocks. There was no indication of an affect on social behavior or individual health of the birds. This study provides support that Flight Control is a safe and effective field repellent.

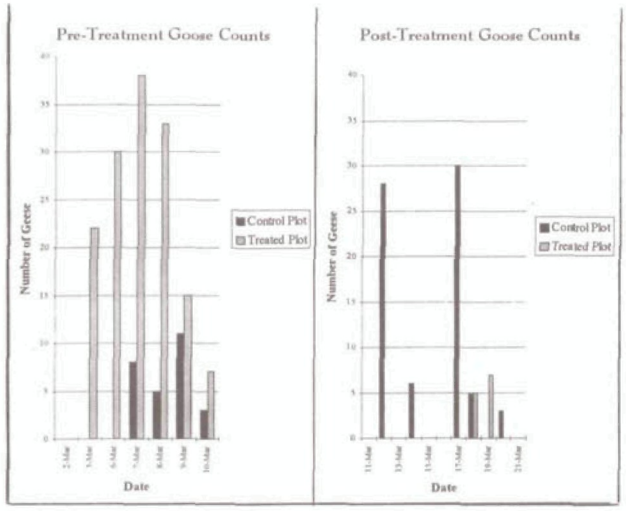

Figure 1. Pre- and post-treatment Canada goose dropping counts on plots during a study using Flight Control conducted in Fort Collins, Colorado.

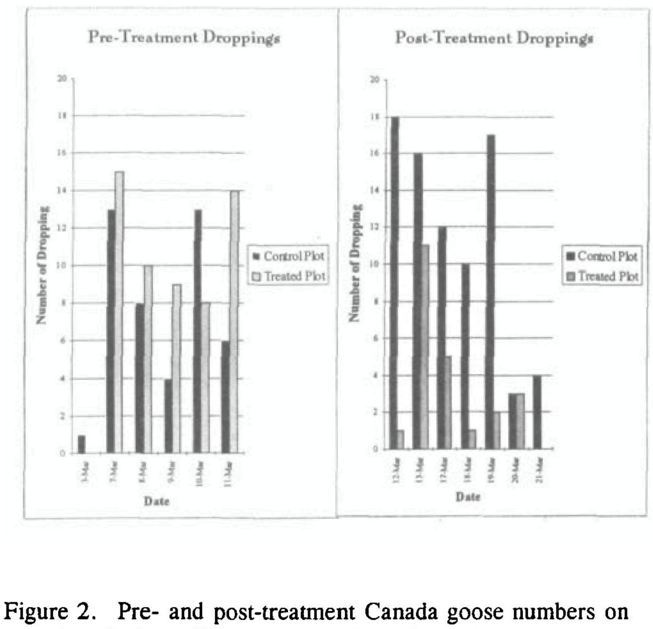

Figure 2. Pre- and post-treatment Canada goose numbers on test plots during a field test with Flight Control.

Table 1. Number of droppings found on transects at Woodward Governor during the pre-treatment and post-treatment periods of the repellency test.

Date	Number of Droppings Pre-treatment		Comments
	Treated Plot	Control Plot	
2/21/97	0	0	
2/22/97	7	0	
2/23/97	0	0	5" of snow
2/25/97	44	14	
2/27/97	39	14	
[1]2/28/97	13	1	
3/2/97	---	---	gate locked
3/3/97	0	1	
3/6/97	---	---	1" of snow
3/7/97	15	13	
3/8/97	10	8	
3/9/97	9	4	
3/10/97	8	13	
3/11/97	14	6	
	Number of Droppings Post-treatment		
3/12/97	1	18	
3/13/97	11	16	
3/14/97	---	---	6" of snow
3/15/97	---	---	snow remained
3/16/97	---	---	snow remained
3/17/97	5	12	
3/18/97	1	10	
3/19/97	2	17	
3/20/97	3	3	
3/21/97	0	4	

[1]On the afternoon of February 28, 1997, plots were mapped and moved to another area on the property.

Table 2. Highest number of geese seen on plots at Woodward Governor during the pre-treatment and post-treatment periods of the repellency test.

Date	Treated Plot	Control Plot	Entire Area	Behavior
Pre-treatment				
2/20/97	0	0	30	Feeding and drinking
2/21/97	0	0	5	Feeding
2/22/97	0	0	16	At 1440 approximately 50 geese were observed in the area
2/23/97	0	0	0	Light snow was falling and approximately 5 to 6" covered the plot
2/24/97	---	---	---	3 to 5" of snow
2/25/97	0	0	54	Feeding and territorial fights occurring
2/26/97	---	---	---	3 to 5" of snow
2/27/97	21	0	40	Feeding and resting, occasional territorial fights
[1]2/28/97	0	0	56	Feeding
3/1/97	---	---	---	6" of snow
3/2/97	0	0	55	Feeding
3/3/97	22	0	62	Feeding
3/4/97	---	---	---	2.4" of snow
3/5/97	---	---	---	2" of snow
3/6/97	30	0	74	Feeding and resting, courting behavior is increasing
3/7/97	38	8	72	Feeding
3/8/97	33	5	63	Feeding
3/9/97	15	11	11	Feeding
3/10/97	7	3	71	---
Post-treatment				
3/11/97	0	0	3	Feeding, plot sprayed
3/12/97	0	28	0	Feeding, plot sprayed again
3/13/97	0	0	28	Feeding
3/14/97	0	6	9	Feeding and resting
3/15/97	0	0	50	Feeding and resting
3/16/97	0	0	16	Feeding and resting, snow covering the plots
3/17/97	0	30	10	Feeding
3/18/97	5	5	39	5 geese crossed treatment plot, 2 of 5 grazed lightly with no apparent effect
3/19/97	7	0	0	Feeding, grass mowed yesterday
3/20/97	0	3	12	Feeding
3/21/97	0	0	8	---

[1]On the afternoon of February 28, 1997, the plots were mapped and moved to another area on the property.

Table 3. Means of highest number of geese seen on plots at Woodward Governor; March 2, 1997 to March 21, 1997.

Plot	Mean	Standard Deviation	[1]Percent Efficacy
Pre-treatment treated	20.71	13.02	95.17%
Post-treatment treated	1.00	2.27	
Pre-treatment control	3.86	4.05	-312.18%
Post-treatment control	15.91	15.59	

Table 4. Means of the number of droppings found on the transects at Woodward Governor; March 2, 1997 to March 21, 1997.

Plot	Mean	Standard Deviation	[1]Percent Efficacy
Pre-treatment treated	9.33	4.89	64.74%
Post-treatment treated	3.29	3.49	
Pre-treatment control	7.50	4.43	-52.40%
Post-treatment Control	11.43	5.65	

[1]To calculate percent efficacy, the following formula was used:
% Efficacy = Pre-Treatment Activity - Post-Treatment Activity X 100 Pre-Treatment Activity
A negative number denoted an increase in activity.

POTENTIAL BIRD REPELLENTS TO REDUCE BIRD DAMAGE TO LETTUCE SEED AND SEEDLINGS

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ABSTRACT: The authors evaluated the effectiveness of ReJeX-iT® AG-145, Mesurol®, activated charcoal, lime, and fipronil to reduce horned lark damage to lettuce seeds and seedlings. In Experiment 1, horned larks consumed significantly more feed mixture (50:50 grains and lettuce seed) than untreated clay-coated lettuce seed in a three-day choice-test. In Experiment 2, where clay-coated lettuce seed was treated with ReJeX-iT® AG-145, Mesurol®, activated charcoal, or lime, there was no significant difference in consumption of untreated clay-coated lettuce seed and treated clay-coated lettuce seed. Horned larks consumed insignificant amounts of all seed treatments including untreated coated lettuce seed. In this experiment horned larks lost an average of 28% of their body weight over the three-day test period. It was concluded that the clay seed coating alone reduced damage significantly. In the aviary test, flats of sprouting lettuce seedlings were sprayed with Mesurol® (4 kg/ha), ReJeX-iT® AG-145 (64 kg/ha), lime (32 kg/ha), activated charcoal (32 kg/ha), and fipronil (4 kg/ha). Mesurol®, ReJeX-iT® AG-145, and lime significantly reduced consumption of lettuce seedlings over a four-day test period. Even though lime significantly reduced consumption, horned larks still consumed over 50% of the available lettuce seedlings. Field evaluations are warranted with Mesurol® and ReJeX-iT® AG-145.

KEY WORDS: activated charcoal, *Eremophila alpestris*, fipronil, horned lark, lime, methyl anthranilate, Mesurol®, methiocarb, ReJeX-iT® AG-145, repellents

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INTRODUCTION

Lettuce (*Lactuca sativa L.*) is an important economic crop in California, with approximately 77,000 ha in production and a value of $735 million in 1996 (California Farm Bureau Federation web page, 1998). Bird damage to recently planted crops is a major problem in several of California's lettuce producing areas, including the San Joaquin Valley, the central coast, and southern California. Annual losses due to bird damage is estimated at $4.6 million; this figure is based only on the amount invested at time of seedling emergence (Mark Arnold, pers. comm.). Actual losses in years of high market value could be several times greater. Forty-five percent of growers responding to a questionnaire survey regarded bird damage as a serious problem (DeHaven 1974).

The major damaging species is the horned lark (*Eremophila alpestris*) which takes the seeds, uproots seedlings and grazes seedling leaves (cotyledons). Damaged seedlings that are not uprooted will usually be stunted or disfigured. In the past, growers have used hazing methods such as shooting and propane exploders to alleviate damage, but few believed these methods to be effective. The current method of choice is hazing by shooting, which costs around $120 per hectare and provides a questionable level of protection against horned larks. Although practically all growers use shooting to haze horned larks, annual losses are estimated at 1,500 ha. The need exists for an effective, economical, and environmentally safe repellent to deter horned lark damage to lettuce seeds and seedlings. One compound that showed promise as a seed treatment or foliar spray on lettuce seedlings was Mesurol®, a product containing methicarb. However, field testing showed inclusive results (DeHaven 1975). At present, Gowan Company, Yuma, Arizona is resuming product registrations for Mesurol®.

Other potential compounds are ReJeX-iT® AG-145, product containing methyl anthranilate, activated charcoal, lime and fipronil. ReJeX-iT® AG-145 is registered with the Environmental Protection Agency (EPA) as an avian repellent for small fruit (PMC Speciality Group, Cincinnati, OH). Evidence indicated that methyl anthranilate at concentrations between 0.5 and 2% is an effective repellent to most bird species (Mason et al. 1989; Cummings et al. 1992). Activated charcoal mixed in with a preferred food of starlings decreased consumption (Mason and Clark 1994). In addition, when applied in a slurry to 0.25 ha winter wheat plots it significantly reduced snow goose use (Mason and Clark 1995). Lime mixed with millet or whole-kernel corn at 25%, 12.5%, and 6.25% reduced brown-headed cowbird and Canada goose feeding in choice cage trials (Belant et al. 1997). Also, application of lime to enclosed 10 x 10 m grass plots in slurry form at an application rate of 544 kg/ha reduced goose feeding on treated plots for two to three days (Belant et al. 1997). Anecdotal observations indicate that fipronil may also show some bird repellency.

The purpose of this evaluation was to test the bird repellency of five candidate compounds: ReJeX-iT® AG-145, Mesurol®, activated charcoal, lime, and fipronil to horned larks when applied to lettuce seed and seedlings in an aviary setting. Concurrently, the phytotoxicity of each compound was evaluated.

METHODS

Over 150 horned larks were captured during April and May 1995 in eastern Colorado for use in this study.

Equal numbers of birds were housed in each of four outdoor pens with access to mixed grains, meal worms and water. Horned larks were quarantined for 30 days before study initiation.

Cage Test

Experiment 1: Thirty experimentally naive horned larks were randomly selected, weighed, banded, and each assigned one per cage (27 cm x 27 cm x 40 cm). During the three-day preconditioning period, the birds were offered two cups with 10 g each of feed mix. The feed mix was 4 parts millet, 1 part wheat, and 1 part cracked corn mixed 1:1 with untreated lettuce seed. Immediately following the preconditioning period, on each of three test days between 0700 and 1300 h, horned larks were offered two cups, one with 20 g of the feed mix and one with 20 g of clay-coated lettuce seed. The position of the cups was switched each day to reduce location bias. A pan was placed under each cage to catch spillage. At the end of each 6 h test period, consumption was measured. Throughout the preconditioning period and test period, horned larks were offered water *ad libitum*. Each horned lark was weighed at the end of the test. An analysis of variance (ANOVA) was used to determine if there were differences between treatments. Linear contrasts were used to test whether mean consumption of feed mix during the preconditioning period and the test period was different, and whether mean consumption of feed mix and clay-coated lettuce seed during the test period was different.

Experiment 2: Thirty experimentally naive horned larks were randomly selected, weighed, banded, and assigned one per cage (27 cm x 27 cm x 40 cm). After a three-day acclimation period to cages, groups of six birds were randomly assigned one of the following treatment groups: control, ReJeX-iT® AG-145, Mesurol®, lime, and activated charcoal. The control was untreated clay-coated lettuce seed and the other treatments were lettuce seeds treated at 1% (wt/wt) of the respective chemical and then clay-coated. On each of three test days, horned larks were offered a cup containing a respective treatment between 0700 and 1300 h. A pan was placed under each cage to catch spillage. At the end of each 6 h test period, consumption was measured. Throughout the preconditioning period and test period, horned larks were offered water *ad libitum*. At the completion of the test, horned larks were weighed. An ANOVA was used to test if there were differences between treatments.

Aviary Test

Flats of lettuce seedlings were grown in a greenhouse and used in the test when they were 0.4 cm tall. Flats of untreated lettuce seedlings were offered to birds for a two-day preconditioning period. Each flat of lettuce seedlings were sprayed just prior to inclusion into the test with a hand-held sprayer calibrated to the respective chemical application rate. Thirty experimentally naive horned larks were randomly selected, weighed, banded, and assigned one per cage (2 m x 2 m x 2 m) with six birds per treatment. Each group of six birds was randomly assigned one of the following treatments: activated charcoal (32 kg/ha), fipronil (4 kg/ha), lime (32 kg/ha), ReJeX-iT® AG-145 (64 kg/ha), and Mesurol® (4 kg/ha). The test was conducted for four days from 0700 to 1300 h. During the test period, maintenance food was removed and only a flat of lettuce was available to each bird. Flats contained an average of 76 seedlings (range 40 to 128). The number of viable lettuce seedling remaining were recorded each day. Throughout the preconditioning and test period horned larks were offered water *ad libitum*. Immediately following the aviary test, all horned larks were weighed, banded, and released.

Analysis of data for each treatment was conducted separately. An analysis of variance (ANOVA) with repeated measures over days was used to determine if there was a treatment effect (SAS Institute Inc., Cary, NC). Only the final day of each preconditioning period was used in the analysis. Significance was set at $P < 0.05$.

RESULTS

Cage Test

Experiment 1: Overall, horned larks consumed significantly less clay-coated lettuce seed ($F_{31,238} = 52.00$, $P < 0.01$). Mean consumption of feed mix during the preconditioning period was 3.3 g/bird. During the test period horned larks consumed a mean of 4.8 and 0.2 g/bird of feed mix and clay-coated lettuce seed, respectively (Figure 1). Mean consumption of feed mix during the preconditioning period was significantly less than the test period ($F_{1,238} = 149.43$, $P < 0.01$). Mean consumption of feed mix was greater than clay-coated seed ($F_{1,238} = 1413.09$, $P < 0.01$). Mean weight loss of horned larks during the test period averaged 3.4%.

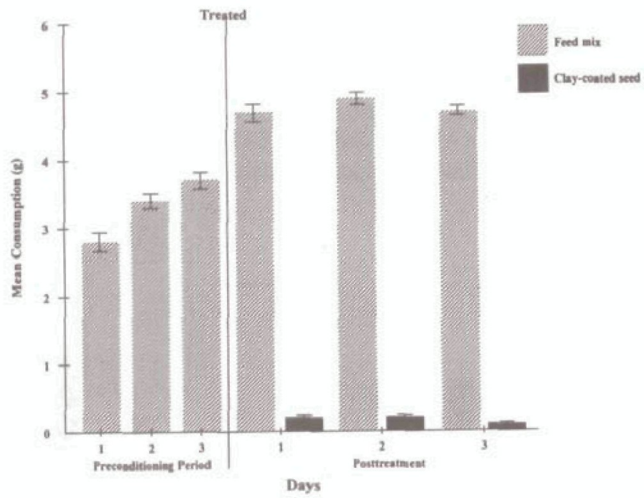

Figure 1. Experiment 1: Horned lark consumption of untreated clay-coated lettuce seed in a choice test. Capped vertical lines represent standard errors.

Experiment 2: There were no significant differences in mean consumption of untreated clay-coated lettuce seed or treated clay-coated lettuce seed ($F_{4,85} = 2.04$; $P = 0.09$). Mean consumption of untreated clay-coated lettuce seed was 2.2 g/bird or treated with 1% ReJeX-iT® AG-145 (a.i.), 1% Mesurol® (a.i.), 1% lime, and 1% activated charcoal was 1.4, 1.1, 0.9, and 0.7 g/bird, respectively. Mean weight loss of horned larks during the test period averaged about 28%.

Aviary Test

Mesurol® significantly reduced horned lark consumption of lettuce seedlings ($F_{1,20}$= 603.46, $P<0.01$). Overall consumption of lettuce seedlings treated with Mesurol® was <0.1 seedlings per horned lark on day 4 of the test. ReJeX-iT® AG-145 and lime also reduce horned lark consumption of lettuce seedlings ($F_{1,20}$= 68.55, $P<0.01$) and ($F_{1,20}$= 27.06, $P<0.01$), respectively. On day 4 of the test, horned larks consumed 0.5 ReJeX-iT® AG-145 treated lettuce seedlings per bird, where as they consumed about six lime treated lettuce seedlings per bird (Figures 2 and 3).

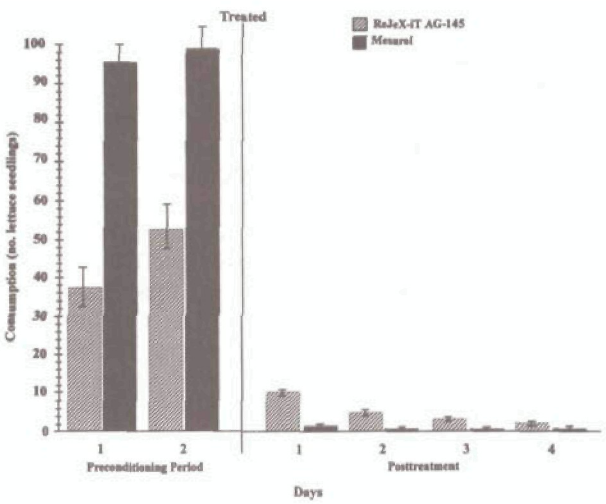

Figure 2. Horned lark consumption of lettuce seedlings sprayed with Mesurol® at 4 kg/ha and ReJeX-iT® AG-145 at 64 kg/ha. Capped vertical lines represent standard errors.

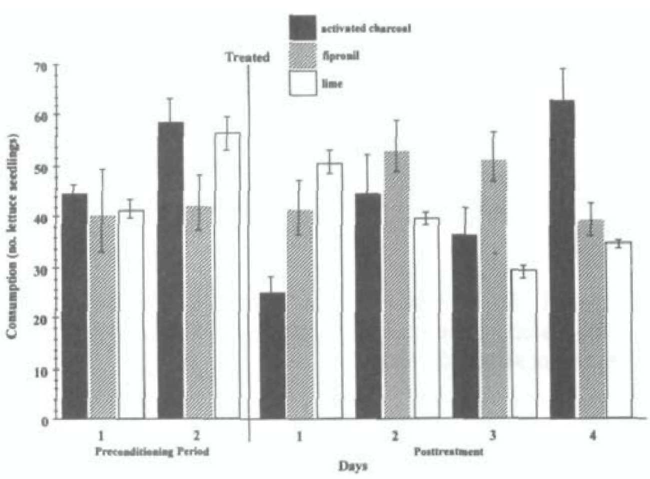

Figure 3. Horned lark consumption of lettuce seedlings sprayed with activated charcoal at 32 kg/ha, fipronil at 4 kg/ha and lime at 32 kg/ha. Capped vertical lines represent standard errors.

Activated charcoal or fipronil did not reduce consumption of lettuce seedlings by horned larks ($F_{1,20}$= 2.96, P=0.10 and $F_{1,20}$= 0.36, P=0.55), respectively. On day 1 of the test, activated charcoal significantly reduced lettuce seedling consumption by horned larks. However, horned lark consumption of treated lettuce seedlings was slightly greater than preconditioning levels by day 4 of the test (Figure 3). Horned lark consumption of fipronil treated seedlings remained relatively constant throughout the test period (Figure 3). Lettuce seedlings phytoxicity was not observed from any chemical used in this test.

DISCUSSION

Cage tests indicated that current procedures of clay-coated lettuce seed prior to planting has a significant effect on reducing lettuce seed loss by horned larks. Limited consumption of the clay-coated lettuce seed was attributed to the difficulty horned larks had cracking the coating and extracting the seed. Dolbeer and Ickes (1994) showed that blackbirds consumed less rice seed that was coated with Portland cement or plaster (50% g/g). Daneke and Decker et al. (1988) also showed that coating rice seeds with clay and starches reduced bird damage. Both summarized that handling time made coated-seeds less attractive to birds. When only clay-coated lettuce seed was offered to horned larks (Experiment 2) birds lost significant body weight. Since the clay-coating can be thinned or thickened in the coating process it is suggested maximum thickness that will still allow emergence of seedlings be applied to lettuce seed that is planted in areas of high bird damage.

The aviary test indicated that Mesurol®, ReJeX-iT® AG-145, and lime significantly reduced horned lark damage to lettuce seedlings. Even though lime showed statistically that horned lark damage to lettuce seedlings was reduced, it was only a 50% reduction. Results of Mesurol® and ReJeX-iT® AG-145 are consistent with other studies where both reduced bird damage to seeds, grapes, cherries, and grass (Fuller et al. 1984; Guarino 1972; Dolbeer et al. 1974; Mason and Clark 1995; Cummings et al. 1995). Activated charcoal has been shown to be repellent to birds in the laboratory (Mason and Clark 1994) and in the field (Mason and Clark 1995). However, this test showed that at a rate six times higher than used for Canada geese and starlings, it was not effective in reducing horned lark damage to lettuce seedlings. Explanations why activated charcoal was ineffective might be due to horned larks being unresponsive to its texture, abrasive or osmotic effects (Mason and Clark 1994). Fipronil did not deter horned larks. It appears that the poor results might be attributed to the low concentration.

Mesurol®, ReJeX-iT® AG-145, and lime are registered with the Environmental Protection Agency. Uses as bird repellent on seedlings (lettuce, tomato, etc.) are warranted. The cost for a field application using our rates would be \$160/ha for Mesurol®, \$190/ha for ReJeX-iT® AG-145 and \$3/ha for lime. The low cost of lime makes it very attractive as a bird repellent. Large-scale field evaluations for each chemical are warranted.

ACKNOWLEDGMENTS

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DEVELOPMENT OF SEED TREATMENTS TO CONTROL BLACKBIRDS

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ABSTRACT: Bird repellents to protect seeds are a potentially important aspect of integrated vertebrate pest management strategies. Yet, there currently are no repellents registered for seed treatment uses. This is due not to lack of effective candidate compounds, but to monetary and regulatory constraints that inhibit commercialization of promising compounds. Two examples of this dilemma are methiocarb and anthraquinone, each of which has considerable potential for bird repellent uses and each of which faces considerable registration hurdles as prospective seed treatment compounds. A concerted, coordinated effort among private industry, producer groups, and state and federal agencies may be the best strategy to bring potentially useful repellents to commercial reality.

KEY WORDS: *Agelaius phoeniceus*, anthraquinone, bird repellent, boat-tailed grackle, crop protection, feeding deterrent, *Quiscalus major*, red-winged blackbird, rice, seed treatment

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INTRODUCTION

For centuries, growers of agricultural crops have treated their seed to ward off depredating birds. European settlers in eastern North America observed Native Americans applying extracts of Veratrum to corn seed as a repellent against crows, starlings and other birds (Benson 1966). The roots of the plant contain various alkaloid compounds (Viehoever and Clevenger 1922), and these probably produced the observed reactions of the birds.

The concept of applying repellent to seed is appealing for several reasons. The chemical is used efficiently because it is actually delivered to the target animals; i.e., those that feed on the seeds. By definition, a repellent is nonlethal, so their use is appealing on ethical grounds. Because many depredating species feed in flocks, there is the opportunity for social learning (Mason and Reidinger 1982), and in some situations, birds directly affected by a repellent can influence the behavior of those that have not, thereby extending the effect of the treatment (Avery 1994; Avery et al. 1995).

Despite the many appealing qualities, there has been surprising lack of approved, effective seed treatment products available to producers. There currently is no compound registered nationally as a bird-repellent seed treatment (S. Wager-Pagé, APHIS Pesticide Registration, pers. comm.). In September 1997, Gowan Company applied to the USEPA for a Section 3 label for methiocarb as a hopper box treatment on corn seed. In February 1998, the EPA proposed to revoke the tolerance on corn seed as of April 1, 1998. Nevertheless, several southeastern and midwestern states issued special local needs (24C) labels for the hopper box corn seed treatment for the 1998 growing season (M. Arnold, Gowan Co., Yuma, Arizona, pers. comm.).

The lack of a registered bird-repellent seed treatment is not due to lack of candidate materials. In cage and pen tests, the authors have evaluated many compounds as seed treatments against blackbirds and other species (e.g., Avery et al. 1994, 1996, 1997). These compounds included registered agricultural chemicals (Kocide, imidacloprid), approved food additives (methyl anthranilate, methyl cinnamate), and naturally occurring plant defense compounds (pennyroyal oil, caffeine). Despite the apparent effectiveness of many of these chemicals, none has become a registered bird-repellent seed treatment.

Discovery and identification of candidate of bird-repellent chemicals is just the first step in a long process that culminates in public use of a product (Mason and Clark 1992). Throughout the process, numerous decisions affect the ultimate fate of candidate materials. Since 1996, the authors have focused research efforts and conducted a variety of trials to evaluate the usefulness of two familiar compounds as potential bird-repellent rice seed treatments.

Methiocarb was originally developed by Bayer scientists in Germany as an insecticide, but testing soon revealed its potential as a bird repellent (Hermann and Kolbe 1971). In the United States, methiocarb was tested extensively as a bird repellent for numerous applications, including rice seed treatment (Holler et al. 1982, 1983). As a result, a Section 3 label application was submitted to USEPA, and emergency use permits (Section 18) were issued in 1983 and 1984 for methiocarb as a rice seed treatment (Holler et al. 1983). The Section 3 label was not obtained, however, and the rice seed treatment remained unavailable.

Recently, Gowan Company purchased the rights to methiocarb from Bayer and began to investigate re-establishing bird repellent applications. The Mesurol® 75% seed treater formulation used in earlier studies (Holler et al. 1982, 1983) was no longer available, however. Instead, Gowan decided to examine the possibility of using the 75% wettable powder (WP) or 50% hopper box (HB) formulation on rice seed. Furthermore, the technology of treating and planting rice seed has changed since the earlier field trials, and it is not clear how such changes affect repellent performance. One significant change concerns soaking the seed prior to planting. Previously, seed was treated dry, and then soaked to stimulate germination before actually being flown onto flooded fields. Current practices for water-seeded rice call for seed to be treated dry and flown onto the fields without presoaking or for rice to be treated after it is soaked and germinated. These changes were mandated by environmental regulations governing disposal of the water in which chemically-treated seed was soaked. Thus, the authors conducted cage and pen studies and limited field trials to evaluate the effectiveness of the 75% WP and 50% HB formulations.

For many years, anthraquinone has been recognized as an avian feeding deterrent. The first United States patent was obtained in 1944 (Heckmanns and Meisenheimer 1944), and early bird repellent uses emphasized protection of pine and rice seeds (Royall and Neff 1961). In extensive evaluation of potential rice seed treatments, Neff and Meanley (1957) considered anthraquinone the standard against which other potential bird-repellent chemicals were compared. Despite generally favorable results, anthraquinone was never registered as a bird repellent in the U.S. Recently, however, Environmental Biocontrol International (EBI), Wilmington, Delaware, initiated an effort to register and commercialize anthraquinone as a bird repellent.

The authors' latest research on methiocarb and anthraquinone was motivated by the renewed interest of private industry to commercialize these compounds as bird repellents. The studies reported here were conducted to support the eventual use of these compounds as registered rice seed treatments.

METHODS

Cage Trials

Methiocarb formulations (75% WP and 50% HB) were provided by Gowan Company. The authors obtained technical grade 9,10-anthraquinone (Chemical Abstracts Service Registry No. 84-65-1) from Aldrich Chemical Company, Milwaukee, Wisconsin. Purity was listed as 97%. Formulated anthraquinone was provided by ABCO Industries, Inc., Roebuck, North Carolina, and Environmental Biocontrol International (EBI), Wilmington, Delaware. Each product contains 50% anthraquinone, by weight. The ABCO product is used in the paper industry. The EBI product is being developed specifically as a bird repellent.

The authors treated rice seed that had been soaked and presprouted by mixing the appropriate amount of chemical with 25 ml of a commercial adhesive and then applied the mixture to 1 kg of rice seed in a rotating tumbler. An exception was the methiocarb 50% HB formulation which was mixed with corn oil instead of a commercial adhesive, according to instructions provided by Gowan. Treated seed was stored in an air-conditioned lab until used.

Birds were captured in decoy traps in Alachua County, Florida, and housed by species in communal cages (1.2 x 1.2 x 1.7 m) in a roofed outdoor aviary two to six months before testing. Unless otherwise stated, birds had free access to water and maintenance food, Quail Starter (Hillandale Farms, Lake Butler, Florida).

The authors removed birds from holding cages, determined mass, and assigned them at random to form treatment groups. After three days of acclimation to the smaller cages, the birds were tested for three hours on four consecutive mornings. The authors removed maintenance food at 0700 and presented test food at 0800. Aluminum pans suspended beneath each cup caught spillage. Food cups containing each treatment were placed in vacant cages to determine moisture gain or loss. The authors removed test food at 1100, replaced the maintenance food, and determined consumption by subtraction, after correction for spillage and changes because of moisture. After the final test day, the authors determined mass, banded, and released each bird.

The authors tested male red-winged blackbirds (*Agelaius phoeniceus*) ($\underline{n}$ = 6 birds/level) with rice seed treated with technical anthraquinone at 0.10, 0.25, and 0.50% (g/g), and at 0.5% and 1.0% with each of the formulated products. They also tested female boat-tailed grackles (*Quiscalus major*) with technical anthraquinone at 0.50% ($\underline{n}$ = 8 birds) and at 1.0% ($\underline{n}$ = 5) using the ABCO formulation. Red-winged blackbirds were given rice seed treated with 75% WP or 50% HB methiocarb formulations at rates of 0.05% and 0.1% (a.i.). They tested grackles with the 75% WP formulation only.

The authors evaluated rice seed consumption among treatments and days in two-way repeated measures analysis of variance (ANOVA). They used Tukey's HSD test (Steel and Torrie 1980) to isolate differences ($\underline{P}$ < 0.05) among means.

Field Trial

At each of four study sites in southwestern Louisiana, the authors established a five acre treated plot and a nearby five acre control plot. At two sites, the treated plots were sown with seed treated with methiocarb at the rate of 0.1% mixed 50:50 with untreated rice. Research conducted in the 1980s demonstrated that total seed treatment with methiocarb was extremely effective in reducing blackbird damage, and the authors did not feel it necessary to repeat those trials. Rather, it was more important to determine if aquatic residue levels of methiocarb could be reduced and efficacy maintained by using a mixture of treated and untreated seed. Aquatic residues are a major concern to the EPA, and any means of reducing them could facilitate the registration process. The other two sites were used to evaluate anthraquinone-treated rice at the rate of 1.0% (a.i.).

The authors seeded all plots at 100 lb/acre with Lafitte foundation seed stock provided by the Louisiana State University Rice Research Station, Crowley, Louisiana. Seed was treated in 50-lb batches using a rotating seed treatment machine. Seed was treated and planted dry, without presoaking. For anthraquinone, the commercially available industrial formulation, ABCO AQ50® (ABCO Industries Ltd., Roebuck, SC) was used. Methiocarb was in the form of Mesurol® 75% wettable powder, provided by Gowan Co., Yuma, Arizona. In addition, 2.4 ml of Exhalt 800® (PBI-Gordon Corp., Kansas City, Kansas), a tank-mix encapsulator, was added to each 50-lb batch of seed.

Treated seed was then stored in burlap bags and flown onto flooded fields within five days. Samples of treated and untreated seed were put into cloth bags that were placed in the flooded plots when the seed was applied. The bags were retrieved one, three, and five days later for analysis of chemical remaining of the seeds. The condition of the seed in the plots was monitored for germination and the water drained after five days. Bird activity was then documented by recording the numbers of birds in each plot at five minute intervals for one to two hours each day.

Two to three weeks after seeding, sprout density was assessed by counting the number of rice sprouts per square foot at 150 points randomly located on six transects throughout each of the plots. At each study site, the authors compared mean sprout counts from transects in the treated plot with those in the untreated plot by applying one-way ANOVA (Steel and Torrie 1980).

RESULTS

Cage Trials, Anthraquinone

With the technical grade chemical, rice seed consumption by red-winged blackbirds declined substantially at each level. At the 0.5% level, reduction from pretreatment was 84%. Results using the formulated products were similar; at 0.5%, consumption was reduced 86% and 89% with the ABCO and EBI formulations, respectively (Figures 1 and 2).

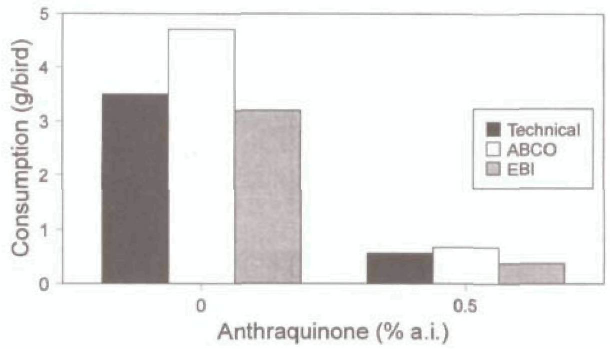

Figure 1. Mean rice seed consumption by individually caged male red-winged blackbirds exposed to seed treated with technical grade anthraquinone, ABCO AQ50, and EBI formulation PCC990. Treatments were at the level of 0.5% active ingredient.

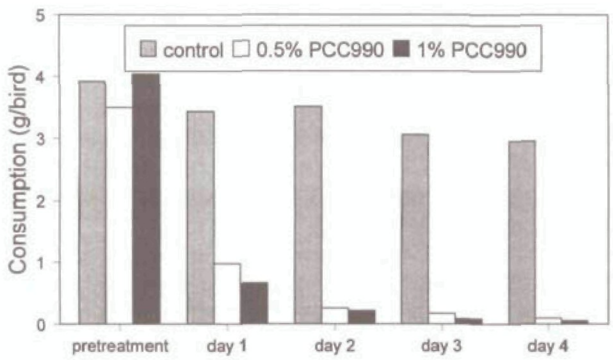

Figure 2. Mean daily rice seed consumption by individually caged male red-winged blackbirds exposed to seed treated with EBI formulation PCC990 at rates of 0.5% and 1.0%.

Boat-tailed grackles exposed to 0.5% (a.i.) technical anthraquinone reduced consumption 73%, from 4.86 g/bird (SE = 0.25) to 1.31 g/bird (SE = 0.13). Using formulated anthraquinone presented at a rate of 1.0% (a.i.), rice consumption by female grackles was reduced 86% with ABCO AQ50 and 94% with the EBI formulation.

Cage Trials, Methiocarb

For red-winged blackbirds, mean reduction in consumption from pretreatment levels using the 75% WP formulation was 89.8% and 92.2% at the 0.05% and 0.1% rates, respectively, compared to 79.2% and 92.5% reductions with the HB50 formulation (Figure 3). Reductions in rice consumption among boat-tailed grackles averaged 93.1% and 96.8% with the 75% WP formulation.

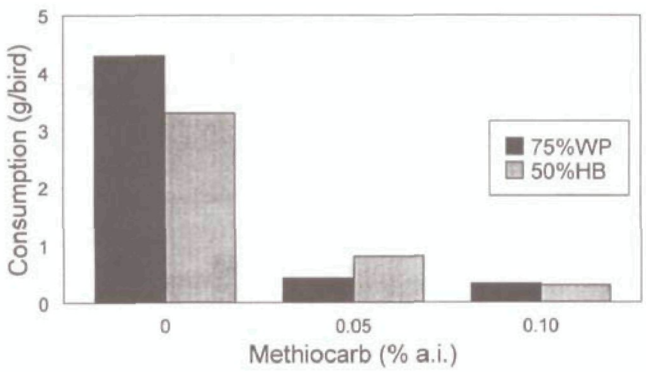

Figure 3. Mean daily rice consumption by individually caged male red-winged blackbirds exposed to seed treated with methiocarb formulations 75% WP and 50% HB.

Field Trial 1997, Anthraquinone

There were obvious, marked differences in sprout density between treated and control plots at each site (Table 1). The treatment effect was especially pronounced at the Taylor site where virtually no sprouts remained in the control plot.

Observations of bird activity at these two sites were consistent with the sprout count results. At the Unkel site, twice as many birds were observed in the control plot ($\bar{x}$ = 28 birds/count, SE = 6) as in the plot treated with AQ50 ($\bar{x}$ = 14, SE = 4). Red-winged blackbirds were predominant at the Unkel site, with brown-headed cowbirds (*Molothrus ater*) and common grackles (*Quiscalus quiscula*) also present. At the Taylor site, birds were far more numerous in the control plot ($\bar{x}$ = 16, SE = 6) than in the treated plot ($\bar{x}$ = 1, SE = 1). Redwings and boat-tailed grackles consistently used the control plot for six days after water was drained, after which birds were seldom observed on either plot.

Analyses of treated seed showed anthraquinone levels of 0.740% to 0.752%. Thus, the amount on the seed was approximately three-fourths of the proposed initial

Table 1. Numbers of rice sprouts counted in one square foot sampling quadrats ($\underline{n}$ = 150/plot) throughout blackbird repellent test plots within the test plots at four locations in southwestern Louisiana, March to April 1997.

		Sprout Density (plants/square foot)			
		Treated		Control	
Repellent	Site	$\bar{x}$	SE	$\bar{x}$	SE
Anthraquinone	Unkel	19.5	2.1	14.6	1.0[a]
Anthraquinone	Taylor	12.4	0.4	0.1	0.1[a]
Methiocarb	Monceaux	18.7	1.4	18.8	1.4
Methiocarb	Sweet Lake	3.8	0.4	0.3	0.1[a]

[a]Statistically significant difference ($P < 0.05$) between treated and control plots.

treatment rate of 1.0%. Anthraquinone remaining on seed placed in the field dropped to approximately 0.61% after 24 hours, but did not decline appreciably during five days in the water.

Field Trial 1997, Methiocarb

Sprout counts were markedly different between the two methiocarb sites. At the Monceaux site, counts were consistently high throughout both plots, whereas at Sweet Lake, counts were very low, especially in the control plot (Table 1). The statistically significant difference in sprout densities between plots at Sweet Lake is relatively unimportant given the very low counts recorded. Bird activity was sporadic at the Monceaux site ($\bar{x}$ = 4, SE = 2) where flocks consisted principally of brown-headed cowbirds and common grackles. Red-winged blackbirds and boat-tailed grackles were usually present in low numbers ($\bar{x}$ = 5, SE = 2) at Sweet Lake, but ibis, little blue herons (*Egretta caerulea*), blue-winged teal (*Anas discors*), and numerous other species of water birds also used the site. Lush aquatic weed growth throughout the plots at Sweet Lake might have contributed to the attractiveness of the site for the nongranivorous species.

Chemical analyses revealed that initial treatment levels ranged from 0.079% to 0.086%, slightly below the intended level of 0.1%. Seed samples placed in the Sweet Lake test plot had 0.0625% methiocarb after 24 hours and then remained stable for five days when the plots were drained.

DISCUSSION

The wettable powder formulation used in the methiocarb trial was not designed for treatment of water-planted rice seed. Although initial levels on the seed were adequate, after the seed was planted sufficient amount the chemical was not retained to deter birds when the test plots were drained. Field trials conducted in Louisiana in the 1980s showed that rice seeds were not protected at methiocarb levels substantially below 0.1%. Thus, low residues (between 0.06% and 0.07%) on treated seed at the Sweet Lake site were probably not repellent which would account for the meager sprout count obtained there (Table 1). Low residues also adversely affected the partial treatment approach employed at the Sweet Lake site. For partial treatment to be effective, birds eating a treated seed must encounter a strong repellent stimulus to deter further sampling of the available seeds (Avery 1994). Evidently, the low methiocarb residues were not sufficiently aversive to support partial treatment.

Because the field results are limited, inferences on the effectiveness of anthraquinone must be made cautiously. Preliminary indications, however, suggest that the anthraquinone treatment very effectively protected seeded rice from blackbird damage. Current information suggests that an anthraquinone-based rice seed treatment will cost <$30/ha (K. Ballinger, Jr., EBI, Wilmington, Delaware, unpubl. data). The relatively low cost suggests that rice can be treated as a prophylactic measure with relatively little expense.

For both compounds, efficacy is not an issue, but regulatory issues remain a major concern. In February 1998, EPA issued a notice of intention to revoke the existing tolerance for methiocarb on corn seed, so the prospects for obtaining a new tolerance for use on rice seed in an aquatic environment appear remote. It is also evident that additional development and testing is needed to produce an acceptable methiocarb seed treatment formulation for water-seeded rice. A tolerance also has to be established for anthraquinone, and it has to be shown conclusively that an anthraquinone seed treatment does not produce harmful residues in the edible portion of the mature crop.

It is unlikely that a repellent for crop use will be registered without substantial involvement of private industry. A company's ability to make a profit will largely determine the extent of its interest in commercialization of a bird repellent. Given the current regulatory climate, it seems likely that partnerships will have to be formed to develop the information necessary to obtain registrations. The best approach at this time seems to be a consortium of private industry, producer groups, and state and federal agencies. This model has been effective in maintaining use of chemical toxicants (Fagerstone 1995), and needs to be seriously considered as a strategy to make safe, effective bird repellents available for public use.

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PREDATOR URINES AS CHEMICAL BARRIERS TO WHITE-TAILED DEER

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ABSTRACT: The authors assessed whether bobcat (*Lynx rufus*) or coyote (*Canis latrans*) urine could reduce white-tailed deer (*Odocoileus virginianus*) use of established feeding areas or trails. A four-week experiment evaluating deer use of eight feeding stations, four each with coyote or bobcat urine was conducted at a 2,200 ha fenced facility in northern Ohio with high deer densities (38/km^2). At this same facility, the authors also monitored deer use of four trails where coyote urine was applied. For both experiments, urine was placed in holders positioned at ground level within 2 m of the area being protected. The number of deer entering feeding stations after two weeks exposure to predator urines was 15 to 24% less ($P < 0.05$) than the number of deer entering feeding stations during pretreatment. Deer use of trails did not decrease in response to presence of coyote urine. It was concluded that predator urines used as a chemical barrier were of limited effectiveness in deterring high concentrations of white-tailed deer from areas with established sources of food and ineffective in deterring deer from trails.

KEY WORDS: *Odocoileus virginianus*, predator urines, repellents, white-tailed deer, wildlife damage management

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INTRODUCTION

Deer (*Odocoileus* spp.) cause substantial economic loss to agricultural crops (Scott and Townsend 1985; Dudderar et al. 1990; Sayre and Decker 1990). Agricultural and wildlife agencies have ranked deer as causing more crop damage overall than any other group of wildlife (Conover and Decker 1991). Deer residing at airport facilities also pose a direct threat to aviation safety. For example, in 1993 to 1995, deer represented 66% of reported civilian aircraft collisions with mammals (Cleary et al. 1996).

Numerous techniques including fences, frightening devices, and repellents have been evaluated or used to reduce deer use of crops and airfields (Craven and Hygnstrom 1994; Belant et al. 1996a). Predator urines have also been evaluated as feeding repellents for mammals (Sullivan et al. 1988; Epple et al. 1993; Nolte et al. 1993, 1994), including deer (Sullivan et al. 1985; Swihart et al. 1991). However, previous studies typically have evaluated the repellency of urine applied directly on or adjacent to the food being protected. Application of urines to forage is undesirable in some situations such as livestock feed or crops for human consumption. To the authors' knowledge, no study has evaluated the effectiveness of predator urines to reduce deer use of specific areas.

The objective of this study was to determine whether predator urines could be used as chemical barriers to reduce white-tailed deer use of established sources of food and trails. The goal was to develop a technique to reduce deer depredation of agricultural crops and livestock food supplies (e.g., stacked hay or silage) and to reduce their presence near airport runways.

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STUDY AREA

This study was conducted during April to June 1996 at the National Aeronautic and Space Administration Plum Brook Station (PBS), Erie County, Ohio. This 2,200 ha facility is enclosed by a 2.4 m high chain-link fence with barbed-wire outriggers. Habitat within PBS differed from the surrounding agricultural area and consisted of canopy-dogwood (*Cornus* spp.) (39%), grasslands (31%), open woodlands (15%), and mixed hardwood forests (11%) (Rose and Harder 1985). During this study, PBS had an estimated minimum white-tailed deer population of 825 ((38/km^2) (P. Ruble, Ohio Div. Wildl., unpubl. data). The deer population was estimated from a helicopter survey which was conducted over the entire facility. Coyotes (*Canis latrans*) are present on PBS; bobcats (*Felis rufus*) are not.

METHODS

Test Materials

The authors obtained coyote and bobcat urine and scent darts from Johnson and Company (Bangor, Maine). Scent darts consisted of six foam strips attached to a 5 cm wood stake and were manufactured specifically to hold urine. Manufacturer recommended use for both urines was to saturate the foam strips of the scent darts and space them at 10 to 12 ft (3.0 to 3.7 m) intervals near the area to be protected. The manufacturer recommended reapplying urine to the scent darts at 10-day intervals. The coyote urine was marketed as effective in moving deer to or away from specific areas; bobcat urine was similarly marketed for small mammals.

Feeding Experiment

Eight deer feeding stations were established, located >1 km apart using whole-kernel corn placed in two adjacent 1.2 m long cattle feed troughs. A 1.5 m high plastic snow fence was erected on three sides of a 5 x 5 m area such that feed troughs were located inside the fenced areas about 1 m from the back. Corn was added to feed troughs as necessary to maintain a constant food supply and the amount of corn added was recorded. An infrared monitoring device (TrailMaster®, Goodson and Assoc., Inc., Lenexa, Kansas was installed 60 cm above ground at each opening to record the number of deer intrusions and to avoid recording nontarget species (e.g., raccoons [*Procyon lotor*], fox squirrels [*Sciurus niger*]).

To condition deer to use feeding stations the authors monitored each station five to seven times per week for one month prior to the experiment, recording the number of intrusions and providing corn as needed. The experiment consisted of a 1-week pretreatment, 2-week treatment, and 1-week posttreatment period beginning April 26, 1996. Feeding stations were identical among periods except that urine was applied to scent darts during the treatment period.

Four sites were selected at random to receive coyote urine; the remaining four sites received bobcat urine. At each site, two scent darts each were saturated with 6 to 8 ml of the respective urine and placed the darts 1 m in front of, and 1.5 m either side of the center of the entrance. During treatment, urine was reapplied every seven days and whenever precipitation exceeded 5 mm within a 24 hr period.

The authors initially divided the daily number of intrusions recorded by the monitoring devices by 2 to determine the number of times deer entered each feeding station. The mean daily number of intrusions/week for each station was then calculated. Analysis of variance (ANOVA) was used with repeated measures (weeks) (SAS Inst. Inc. 1988) on log-transformed data to compare the number of deer intrusions and amount of corn consumed among periods for each type of urine. If main effects were significant ($P < 0.05$), Tukey tests were used to determine which means differed.

Trail Experiment

A TrailMaster was positioned to record deer crossings along each of four trails separated by >1 km. At each trail on May 16, the authors then placed a scent dart 2 m on either side of the monitoring device and <1 m from the trail. The experimental design and statistical analyses were conducted identically to those described for the feeding experiment except that the daily number of deer crossing were not divided by 2.

RESULTS

Feeding Experiment

The mean (± SE) daily number of deer intrusions differed among treatment periods at sites with bobcat urine ($F=4.67$; 3,9 df; $P=0.03$) and coyote urine ($F=28.19$; 3,9 df; $P < 0.01$) (Figure 1). For both urines, the number of deer intrusions was greatest during pretreatment and lowest during posttreatment. For both urines, the mean daily number of intrusions during week 2 treatment was 15 to 24% less than the mean daily number of intrusions during pretreatment.

Mean daily corn consumption also differed at feeding stations with bobcat urine ($F = 5.80$; 3,9 df; $P = 0.02$) and coyote urine ($F = 16.22$; 3,9 df; $P < 0.01$). For both urines, corn consumption was greatest during week 1 treatment.

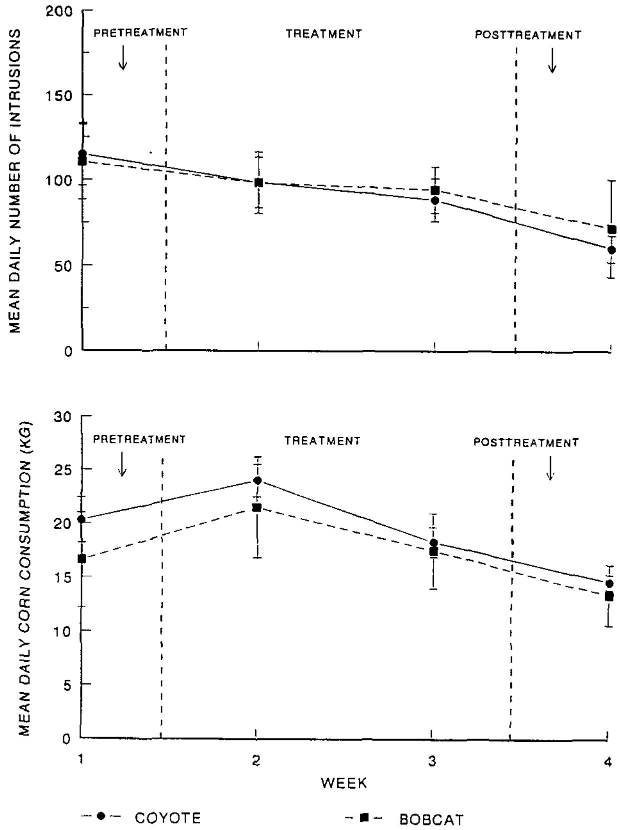

Figure 1. Mean daily number of white-tailed deer intrusions and mean daily corn consumption at sites with coyote or bobcat urine by week, Plum Brook Station, Erie County, Ohio, April to May 1996. Capped vertical lines represent 1 standard error.

Trail Experiment

The mean daily number of deer crossings increased ($F=9.78$; 3,9 df; $P < 0.01$) during the four-week experiment with more ($P < 0.05$) deer crossings during posttreatment (41.3 ± 5.1) than during pretreatment (4.7 ± 1.5) and treatment (7.7 ± 2.0 to 18.6 ± 8.9) (Figure 2). The number of crossings during pretreatment and treatment was similar ($P > 0.05$).

DISCUSSION

The slight (15 to 24%) decline in deer use of feeding stations after two weeks of exposure to bobcat and coyote urine suggests limited effectiveness as a chemical barrier. That deer use continued to decline during posttreatment suggests deer may have learned to avoid the feeding stations. Alternatively, the observed decline in use during April to May may be attributed to increased availability of highly nutritive grass and forbs. Also, decreased use of feeding stations could be in response to decreased movements of female deer during parturition.

Bobcat and coyote urines were marginally effective in deterring white-tailed deer from entering feeding areas and ineffective in reducing deer use of established trails. Sullivan et al. (1985) and Swihart et al. (1991) found that bobcat and coyote urines applied directly on or adjacent

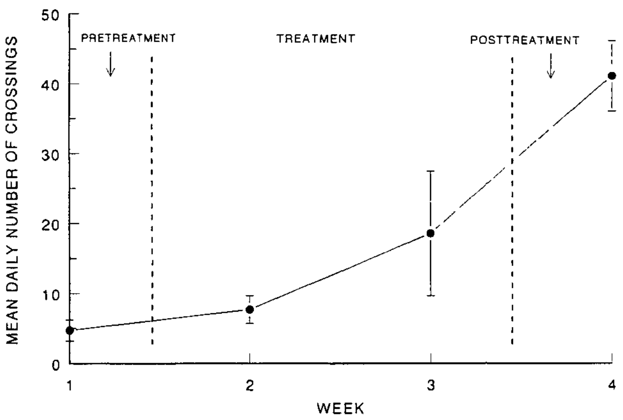

Figure 2. Mean daily number of white-tailed deer crossings on trails at sites with coyote urine, Plum Brook Station, Erie County, Ohio, April to May 1996. Capped vertical lines represent 1 standard error.

to food suppressed consumption by white-tailed deer and black-tailed (*O. hemionus*) deer. In these studies, urine applied directly on food suppressed feeding more than did urine placed adjacent to food. In this study, urine was applied about 5 m from the food. Thus, effectiveness of predator urines increases as the distance between the urine and food source decreases, and effectiveness is maximized when urine is applied directly to food.

The inability of urines to substantially reduce deer intrusions at feeding areas in this study may be related to higher deer densities than observed in other studies; however, the lack of reduction in deer use of trails was likely not. The authors are uncertain why deer use of trails during week 2 treatment and posttreatment increased. One possible explanation is increased movement of female deer to forage post-parturition. Also, the ineffectiveness of using predator odors, such as urine, to deter white-tailed deer from specific areas, such as trails, may not be applicable to mammals in general. For example, Sullivan et al. (1988) documented avoidance by rodents of burrows treated with predator odors. Effectiveness of repellents appears related to the relative attractiveness of the material or area being protected (see Belant et al. 1996b).

Effectiveness of predator urines may also be related to the relative threat perceived by the prey (Swihart et al. 1991). Swihart et al. (1991) suggested that white-tailed deer are more alarmed by the presence of bobcats than coyotes. Aversion to predator odors may be innate, suggesting that habituation should not occur (Muller-Schwarze 1972, 1974). However, habituation to learned avoidance of predator odors may occur if reinforcement is lacking. Bobcats have not been present in northern Ohio for >50 years (Gottschang 1981). Thus, white-tailed deer on PBS may have overcome their innate aversive response to bobcat urine because reinforcement does not occur. The authors have observed coyotes chasing white-tailed deer and carcasses of deer apparently killed by coyotes on PBS; however, the relative importance of deer in the diet of coyotes on PBS is unknown.

Although direct application of predator urines to food can suppress feeding by deer (Sullivan et al. 1988; Swihart et al. 1991), predator urines were only marginally effective in excluding a high-density population of white-tailed deer from establishing feeding areas and were ineffective in reducing deer use of trails. It is concluded that predator urines used as a chemical barrier would be only of limited value in deterring deer from areas containing desired food and from using airport runway areas.

ACKNOWLEDGMENTS

A. L. Bower, Plum Brook Station, granted permission to use study sites. C. R. Bartholomew and S. K. Ickes provided field assistance. Sponsorship and funds for this research were provided by the Federal Aviation Administration (FAA), Office of Airports Safety and Standards, Washington, DC, and Airports Division, Airport Technology Branch, FAA Technology Center, Atlantic City International Airport, New Jersey.

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ARE WILDLIFE-CAUSED LOSSES OF AGRICULTURE INCREASING?

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ABSTRACT: Both the percent of producers reporting and the value of wildlife-caused losses increased from 1989 to 1994. In 1994, 58% of respondents reported wildlife-caused losses of their agricultural commodities, an increase from the 55% of respondents who reported losses in 1989. Based on the median value of producer-estimated loss, wildlife-caused losses cost producers approximately $591 million in 1994, $130 million more than in 1989. Losses based on producer estimates have been consistent with field-measured estimates of damage. While these losses represent 1% of the value of agricultural production, losses were not evenly distributed and 23% of producers estimated losses of >$500, an amount that is psychologically significant if not also economically significant. While catfish losses to wildlife were 4% of the total sale value of catfish in 1996, the losses were equivalent to one-sixth to one-third of the average catfish producers' profit. Producers' ability to predict the location of their crop losses as well as consistent patterns of losses based on field assessments suggests that wildlife managers may be able to develop models of wildlife damage that would allow them to better assist producers in planning agricultural production so that wildlife-caused losses are reduced. Given the increasing populations of many wildlife species and the declining habitat base for supporting those populations, wildlife managers will need to increasingly rely on cooperative relationships with agricultural producers. Management of wildlife damage relative to agricultural needs will increasingly challenge the wildlife profession in the coming years. Wildlife managers must recognize the magnitude and distribution of wildlife-caused damage to agriculture and consider both perceptions and damage in their decisions about wildlife management.

KEY WORDS: agricultural producers, birds, *Canis*, catfish, coyotes, damage, deer, distribution, dollar value, economic value, field crops, fruits, livestock, *Odocoileous*, vegetables, wildlife

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INTRODUCTION

Managers in the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Wildlife Services (WS, formerly Animal Damage Control) believed they lacked information and understanding about wildlife-caused losses of agriculture. They, therefore, contracted with USDA's National Agricultural Statistics Service (NASS) starting in 1989 to assess the percent of producers who had sustained losses from wildlife, the producers' assessment of which wildlife caused the losses, and their estimate of the value of those losses. Most recently, the dollars spent by producers in loss prevention have been assessed and the effectiveness of the Wildlife Services program in helping producers reduce losses has been enumerated. National estimates of wildlife-caused damage to agricultural products were completed in 1989 (Wywialowski 1994) and 1994 (Wywialowski 1997). For livestock assessments, losses to cattle in 1991 were < 0.1% of the value of production (Agricult. Stats. Board 1992), although an estimated 2.87% of beef calves were lost to predators in 1996 (USDA 1997); losses to sheep based on two years data equal 2.5 to 2.7% of the value of production (Agricult. Stats. Board 1991; Simpson 1995); and losses of goats based on a five-state assessment were 3.8% of the value of goats produced in those states (Agricult. Stats. Board 1995a,b). Losses to field corn were measured in 1993 with the value of loss estimated at >$100 million nationwide, but averaging 0.7% of the value of production in the top 10 corn-producing states (Wywialowski 1996). Losses were highly variable among the states measured, with a few producers sustaining substantial losses in some fields. Most recently wildlife-caused losses of catfish were assessed (Wywialowski 1998). Based on cost of production estimates from other sources, an estimated one-sixth to one-third of the average catfish producers' profit went to wildlife. Questions remain on the best means either for producers to minimize their losses, or to redistribute wildlife-derived benefits among producers with regard to wildlife-derived costs.

Except for field measures of wildlife-caused loss to ripening field corn (Wywialowski 1996), all measures of loss are based on producer estimates. While many argue that producers' estimates of losses are biased high, comparisons of field-based measures of wildlife-caused losses with producer-based estimates of wildlife-caused losses indicate that most producers accept minimal losses without reporting them and underestimate any field crop or vegetable, fruit, or nut losses that do occur (see Wywialowski 1994 for an extensive discussion of this issue). The total losses for livestock-poultry producers were similar in 1994 and 1989; these total losses based on producer estimates are consistent with estimates based on field studies and surveys of predation rates, and the number or value of livestock in the United States. Other losses were consistently underestimates based on extrapolation from field-derived measures. Consistent with this idea, the value of field corn documented as lost to wildlife in 1993 as a proportion of the value of all field crops lost to wildlife in 1994 based on producer estimates, was less than the value of field corn as a proportion of the value of all field crops in 1992 (U.S. Bur. of Census 1994), even though the field-measured value is a minimal estimate of actual wildlife-caused losses because many ripening field corn losses that could not be definitively identified as wildlife-caused by inspection of the corn in the late fall were not included as wildlife-caused losses (Wywialowski 1996). The producer-based estimate of field crop losses in this survey at 0.7% of the market value of all field crops mirrors the quantified minimal value of ripening field corn lost to wildlife.

METHODS

For the national estimates of wildlife-caused losses to agriculture, initial samples were 20,001 and 16,000 producers. Wywialowski (1994) provides details on survey methods, as well as means of data analysis and statistical tests used. For most surveys, the sample was stratified randomly by farm size to assure adequate large farm representation as in 1989, or stratified by farm type and randomly selected within farm type to assure adequate sampling of the minor farm types as in 1994. The NASS List Sampling Frame is a computerized and regularly updated list of farm operations within all states from which the samples are selected.

Data were collected from producers using NASS's 11 computer-assisted telephone interview centers. In December, producers were mailed a pre-survey postcard that explained the objectives of the survey and the importance of their participation. Producers were contacted by telephone in January with questions about the preceding year's production and losses. Respondents were asked to consider any wildlife-caused damages to their agricultural resources that resulted in a substantial or significant loss.

Other data collection and analysis procedures for the 1989 and 1994 national surveys follow (Wywialowski 1994). Data were weighted before analysis for each respondent based on the number of usable responses in each state and the number of farms in each state relative to the total number of farms and total number of usable responses. For the calculation of the percentage of producers in each commodity group due to producer-type subsampling in 1994, weights to correct for over-representation of producers of catfish and trout, and other commodities were also used.

Proportions of respondents in commodity groups and proportions of each wildlife group cited to cause losses were compared among regions using the Bonferroni modified least significant difference test with $\alpha = 0.05$. Significant differences between other groups were determined using maximum likelihood ratio chi-square tests (MLR). Differences between 1989 and 1994 were assessed by non-overlap of the 95% confidence intervals for point estimates. Differences in median losses between primary and non-primary farm types were assessed using the Mann-Whitney U test (MWU). All results that follow are statistically significant.

RESULTS and DISCUSSION

All Agricultural Producers

Nationwide, 58% of respondents reported wildlife-caused losses of some commodity, an increase from the 55% who reported losses in 1989. Losses varied among regions (Figure 1). Overall, losses increased from 1989 consistently across most regions (Figure 2), and in most but not all producer groups (Figure 3). In nearly all groups, the producers who received the majority of their income from a commodity type (referred to as primary farm type), sustained proportionately and monetarily greater losses than those producers who produced some of the commodity but did not consider it their primary source of income (Figure 4). This is predictable based on sociological as well as economic aspects of wildlife-caused losses. The dollar values of losses were calculated as described in (Wywialowski 1994) using median losses due to the extremely non-normal distribution of losses (Sokal and Rohlf 1981) (Figure 5). In the 1994 survey, 23% of all producers reported losses >\$500 (Figure 6). Based on the median of producers' estimates of their losses, wildlife-caused losses cost producers approximately \$591 million in 1994 (Figure 7), >\$100 million more than in 1989. If all producers estimated their losses accurately (especially those citing very high values) and their losses represented producers nationwide, then wildlife-caused losses based on the mean of producers' estimates may have been as high as \$1.6 billion in 1994, compared to \$1.3 billion in 1989. Much of these results are from Wywialowski (1997).

Livestock and Poultry Producers

Livestock or poultry (LP) was raised by three-fourths of respondents. Of those who raised livestock or poultry, 21% reported wildlife-caused losses (Figure 8) statistically not different from the 20.4% who reported losses in 1989. Carnivores were cited most frequently by LP producers as causing their losses, of which coyotes (*Canis latrans*) were cited most frequently (11% nationally, ≥20% in three western regions). Carnivores were cited as causing losses most frequently in Texas and least in the Great Lakes. The remaining wildlife groups were cited by ≤2% of all LP producers.

Losses of livestock and poultry estimated by LP producers who reported a loss had a median value of \$400/farm, similar to the \$450/farm in 1989. Based on these estimates, wildlife caused \$140 million in losses for LP producers in 1994, similar to the \$138 million estimate for 1989 (Figure 7).

Field Crop Producers

Field crops (FC) were raised by 81% of respondents, similar to the 83% in 1989. Half (51%) of FC producers said they lost crops to wildlife (Figure 9), a slight increase from the 48% who reported losses in 1989. Hoofed mammals were cited by 41% of FC producers, an increase from 34% in 1989. Rodents and rabbits were cited by 15%, a decrease from 19% in 1989. Birds were cited by 12%, an increase from 9% in 1989. The other wildlife groups did not differ between years.

Deer were the main hoofed mammal cited for FC losses (40% of FC producers) and were the species responsible for the increased citing of hoofed mammals in 1994. The remaining significant changes are consistent with increasing small furbearer (carnivore/omnivore) populations and the consequent decreases in prey abundance, reducing rodent and rabbit losses.

For the 51% of FC producers who had FC losses, the median estimated loss was \$350/farm, up from \$300/farm in 1989. Based on median producer estimates, wildlife caused approximately \$316 million for FC producers in

1994, an increase from the estimated $237 million loss in 1989 (Fig. 7).

Figure 1. Regions of the U.S. used for most of the 1989 and 1994 national surveys.

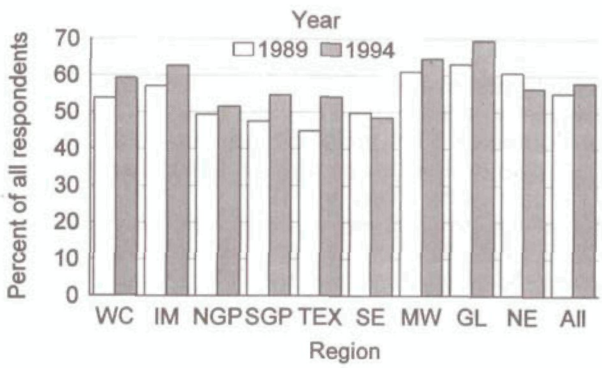

Figure 2. Percent of all respondents with any loss to any wildlife for any commodity by region in 1989 and 1994.

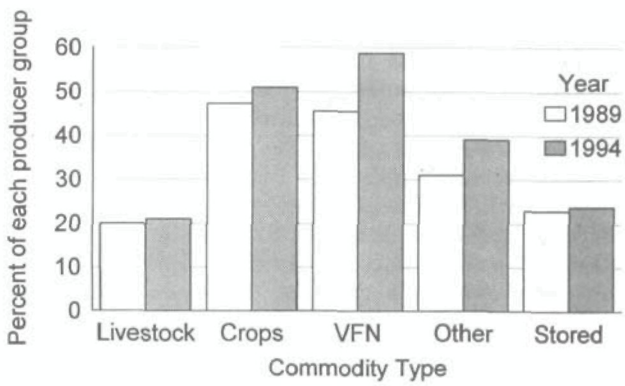

Figure 3. Percent of each producer group with wildlife-caused losses to their commodity type in 1989 and 1994.

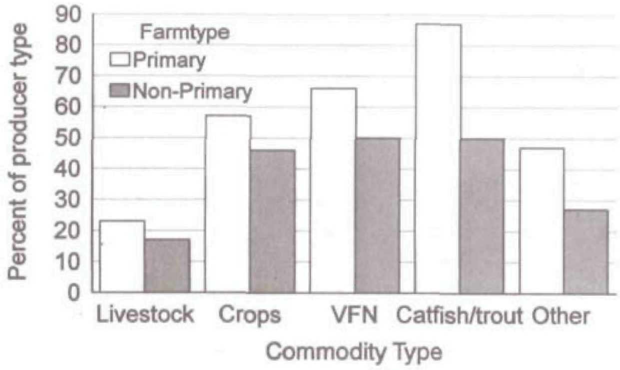

Figure 4. Percent of each producer group with wildlife-caused losses to their commodity type by primary and non-primary farm types in 1994.

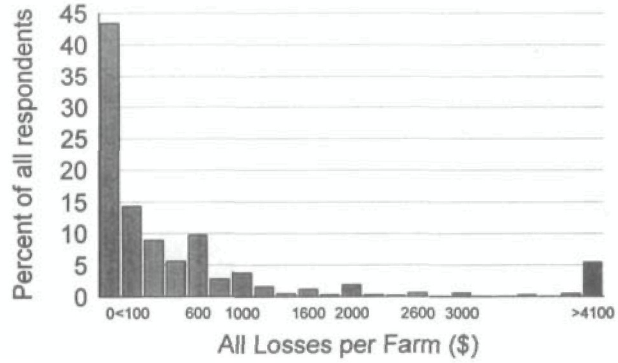

Figure 5. Percent of all respondents by the sum of all wildlife-caused losses for all commodities per farm in 1994.

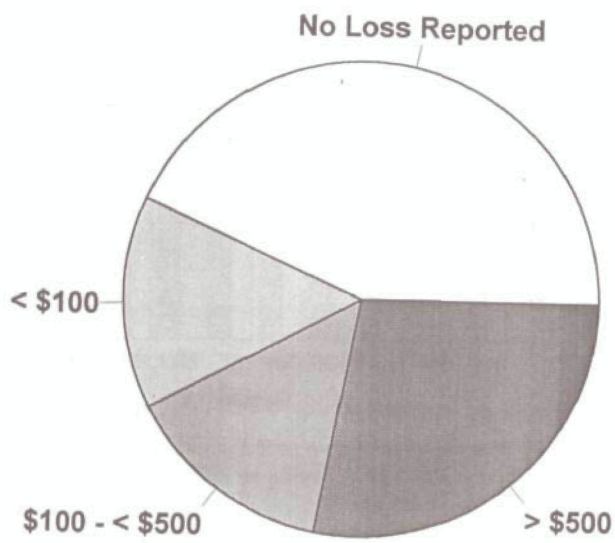

Figure 6. Percent of all producers within a dollar value category of wildlife-caused losses for all commodities per farm in 1994.

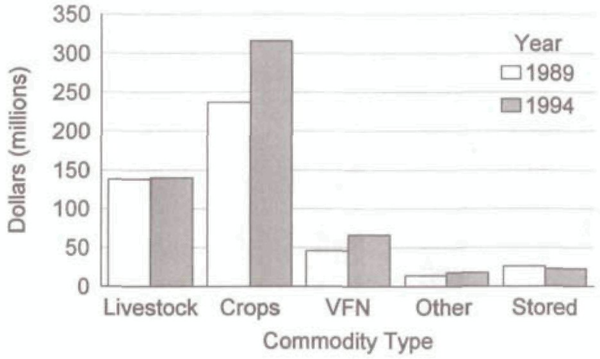

Figure 7. The median-based sum of wildlife-caused losses by commodity types in 1989 and 1994.

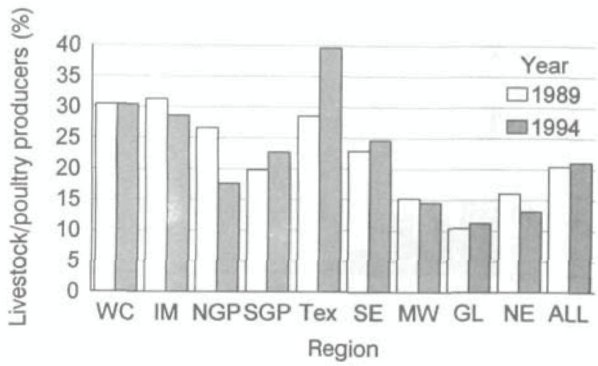

Figure 8. Percent of livestock/poultry producers with wildlife-caused losses of their livestock or poultry by region in 1989 and 1994.

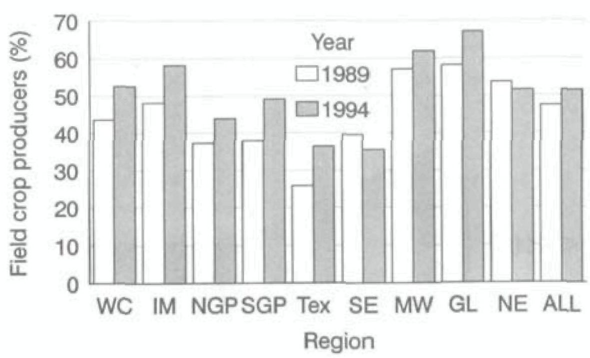

Figure 9. Percent of field crop producers with wildlife-caused losses of their field crops by region in 1989 and 1994.

Producers with Stored Commodities

Nearly half (44%) of respondents stored some whole grain, feed, or seed on their farm; the majority of which were the LP (55%) and FC (43%) farm types. Of respondents with stored commodities, 24% cited losses (Figure 10), of which rodents (primarily mice and rats) or rabbits were most frequently cited as causing losses of stored commodities. The frequency of producers who reported losses of stored commodities to rodents or rabbits varied from 29% in the West Coast to 11% in the Northern Great Plains; but the $23 million and $26 million did not differ between years (Figure 7).

Vegetable, Fruit, or Nut Producers

Of all respondents, 11% raised vegetables, fruits, or nuts (VFN)—a decrease from 19% in 1989, although the reduced proportion of VFN producers is likely due to specifying "commercial" production in the 1995 interview. Regions were larger due to a smaller percentage of VFN producers (Figure 11). Of VFN producers, 59% reported wildlife-caused VFN losses, an increase from 46% in 1989 (Figure 12). Losses of VFN were attributed to a diverse mix of wildlife (Figure 13). The total percent of cited losses as depicted in Figure 13 could exceed 100% because each producer could cite up to five wildlife species that caused losses for each commodity. Rabbits and rodents (primarily squirrels, woodchucks, and gophers) were cited by 28% of VFN producers, up from 20% in 1989. Losses to hoofed mammals (primarily deer) were cited by 25% of VFN producers, up from 17% in 1989. Deer (24%) were the main hoofed mammal cited for VFN losses; and rates were highest in the northeast. Birds were also cited more frequently (21% vs. 17% in 1989), although the proportion of VFN producers who attributed losses to birds did not differ among regions. Omnivores (primarily raccoons) were cited by 10% of VFN producers. Carnivores (primarily coyote) were cited by 5%, up from 2% in 1989. Based on the median estimated loss, wildlife caused $66 million in losses for VFN producers in 1994, more than the $46 million estimated loss in 1989 (Figure 7).

Catfish Producers

When comparing all producer types in 1994, producers who raised catfish or trout reported the greatest wildlife-caused losses (Figure 14). These high rates of loss prompted the author to complete a more detailed survey of losses for catfish producers during 1996 (Wywialowski 1998).

In the 15 states surveyed in 1994, 1,008 catfish producers completed the survey resulting in an 81% response rate for producers. Overall, 69% of catfish producers cited a wildlife-caused loss of their catfish, although losses varied among regions (Figure 15). Producer spent $5 million in loss-prevention costs, and sustained wildlife-caused losses of $12 million, for total costs for catfish producers of $17 million or 4% of the value of catfish sales in 1996. Birds were most frequently cited as a cause of the losses, and double-crested cormorants were most frequently cited (53%), as well as most frequently cited as the primary species causing losses. The next most frequently cited birds were herons (48%), of which 42% cited great blue herons. Other wildlife groups were cited by <20% of producers.

More catfish producers (44%) than other types of agricultural producers were familiar with the federal Wildlife Services (formerly Animal Damage Control or

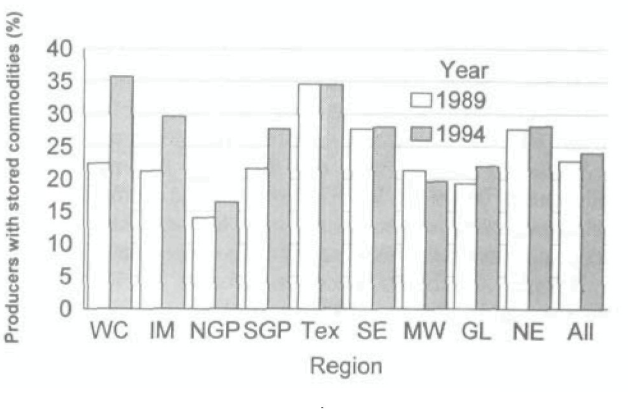

Figure 10. Percent of all producers who stored feed, seed, or grain on their farm and reported wildlife-caused losses of those stored commodities by region in 1989 and 1994.

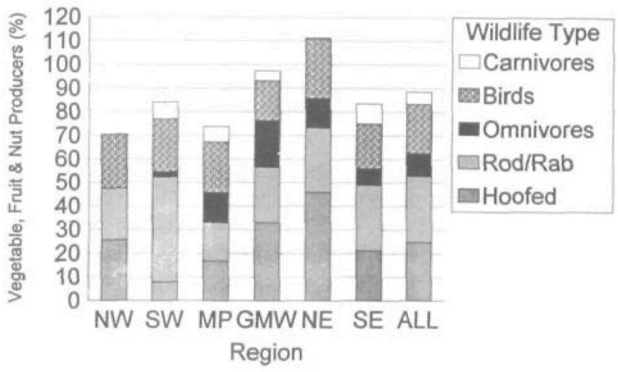

Figure 13. Percent of vegetable, fruit, or nut producers that reported wildlife-caused losses of their vegetables, fruits, or nuts for each wildlife type by region in 1994.

Figure 11. Regions of the U.S. used for analysis of vegetable, fruit, and nut producers in 1989 and 1994 national surveys.

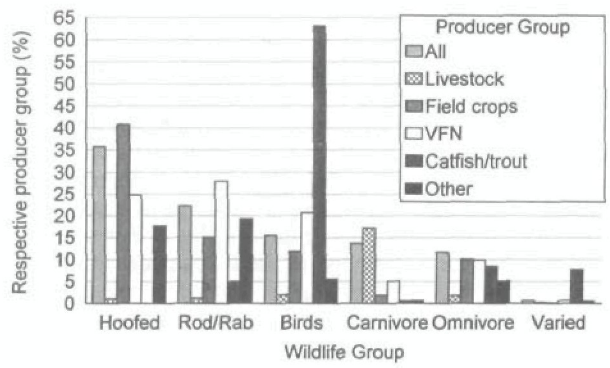

Figure 14. Percent of each producer group that reported wildlife-caused losses of their commodity type for each wildlife type in 1994.

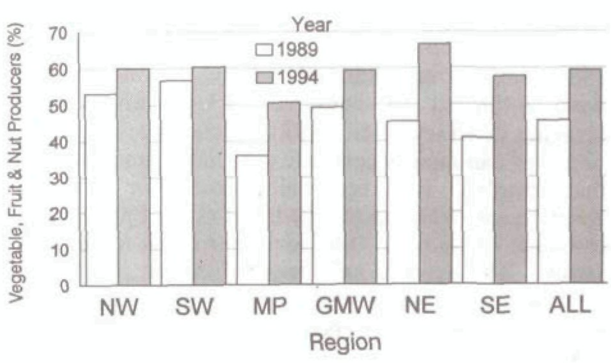

Figure 12. Percent of vegetable, fruit, or nut producers with wildlife-caused losses of their vegetables, fruits or nuts by region in 1989 and 1994.

Figure 15. Regions including all U.S. states used for analysis of catfish production and wildlife-caused prevention costs and losses in 1996.

ADC) program. Mississippi contributed the majority of production, but not the majority of losses. The two areas identified in the 1996 survey in which Mississippi statistically differed from all other regions was that a greater proportion of producers in Mississippi used more direct services from Wildlife Services, and producers used roost dispersal more frequently than in other regions. Other unidentified factors may also play a role but Mississippi catfish producers being more likely to have mid- to low-range preventive costs (preventive costs/total sales) (Pearson's $R = -0.0728$, $p = 0.021$), and least likely to sustain losses in the highest proportion (cost of loss/total sales) of wildlife-caused loss categories (Pearson's $R = -1.132$, $p < 0.001$).

MANAGEMENT RECOMMENDATIONS AND CONCLUSIONS

Successive surveys in 1989 and 1995 indicated that the reported value of wildlife-caused losses increased for some agricultural commodities. The author's conclusions are a discussion of some commonly held misconceptions about wildlife-caused losses of agricultural commodities.

Inequitable Distribution of Losses

Managers must understand that although the proportion of the total value of commodities perceived to be lost to wildlife may be small in comparison to their total value (0.5 to 1.3% overall), losses are not uniformly distributed among producers or commodity types. When the distribution of losses is highly skewed, dismissing all losses because they represent a small percentage of the total national product has limited utility. For example, nationwide, the percentage of field corn lost to wildlife may be less than the amount of corn lost in harvesting operations (Wakeley and Mitchell 1981); however, for the 1% of corn fields with ≥20% lost to wildlife (Wywialowski 1996), production costs probably exceed harvested value. Hence, the low overall percentage does not console farmers with high losses. Some producers of commodities susceptible to high wildlife-caused losses, such as catfish, sheep, goats and fruit, may require assistance to maintain viable operations. As economic conditions or wildlife populations change, perceptions of and concerns about losses may also change (Siemer and Decker 1991; Adkins and Irby 1992). Most producers tolerate some wildlife-caused losses; intolerance begins when losses exceed $500 (Siemer and Decker 1991); 23% of respondents in 1994 fit this criteria.

The estimated value of wildlife-caused loss in 1994 of $0.6 to 1.6 billion is only 0.4 to 1.1% of the $162.6 billion of agricultural products sold in 1992 (the last year for which complete data is available, U.S. Bureau of the Census 1994). However, expenses to produce those agricultural commodities were estimated at $130.8 billion. The average farmer sold $84,459 of products for which cost of production averaged $67,928 (80% of sales) leaving an average farm income of $16,531. For all producers surveyed, the median reported loss was <$100 with a mean of $798 (SE=33), which would be 0.6 to 5% of the average farmer's net income. For farmers who reported losses to wildlife, losses averaged 3 to 8% of the average farmer's net income. Losses were greater for catfish producers at 4% of the value of production, but 15 to 30% of the average catfish producer's profit (dependent on the estimated profit) (Keenum and Waldrop 1988). Most of these surveys have only assessed direct wildllife-caused losses; producers may spend substantial sums protecting their commodities from damage. Further, losses are inequitably distributed among commodity types with assessed losses ranging from <1% to >30% of producer profits. The median-based estimate of losses was one-third of the mean-based estimate of losses of $1.6 billion because a small percent estimated large losses. These high loss estimates may be accurate, however, because wildlife-caused damage is not uniformly distributed among producers (Dolbeer 1980; Besser and Brady 1986; Hothem et al. 1988; Wywialowski 1996).

Problemmatic Wildlife Populations are Increasing

With the exceptions of livestock/poultry, stored commodities and other commodities, percent citing losses and value of losses increased from 1989 to 1994. Both the percentage citing losses and the cost of wildlife-caused losses increase from 1989 to 1994 for field crops, and vegetables, fruits, and nuts. Better sampling of VFN producers may have influenced the results, but the author believes the 1994 estimates more accurately reflect actual losses than the 1989 estimates. Deer populations continue to increase in many states, and appear to be responsible for much of the increased losses between 1989 and 1994.

The production of vegetables, fruits, and nuts was greater in 1992 than in 1987 (U.S. Bur. of the Census 1994), and current diet recommendations and trends suggest that consumption and demand for VFN will continue to increase. Hence wildlife-caused losses of VFN will continue to be a growing problem for wildlife-damage managers.

The proportion of all producers who perceived that they sustained wildlife-caused losses was higher in 1994 than in 1989. The higher estimated losses may result from higher wildlife populations (particularly deer), higher perceptions of damage, and improved sampling of rare producer types.

Effectiveness of Wildlife Services in Reducing Losses

Given the growing numbers of catfish (Tyson et al. 1998), preventive techniques have probably been useful in preventing losses from reaching even higher levels. The 4% value of loss in the top 15 catfish producing states in 1996 mirrors the 4% value reported loss in Mississippi in 1989 (Stickley and Andrews 1989). Cormorant flocks were estimated to consume $13.45/catfish/hour of foraging (Stickley et al. 1992). Hence the large flocks observed can rapidly consume substantial amounts of fish that translate into economic losses for producers. Keenum and Waldrop (1988) found cost of production of catfish to be $0.60 to 0.68 for the smallest to the largest farms. The average sale price of catfish in 1988 was $0.764/pound (NASS 1994); this would give a profit range of 11 to 22%. Hence, the 4% cost of wildlife may range from one-sixth to one-third of farm profits.

The amount of farm-raised catfish processed has increased from 2.6 million kg in 1970 to 206.6 million kg in 1993 (USDA 1994). The 1996 estimated market value of catfish was $424 million (USDA, NASS 1997).

Mississippi catfish producers have had greater support from WS, APHIS, as well as Cooperative Extension and assistance from Mississippi State University; and their efforts better prevented wildlife-caused losses at less cost than catfish producers in other states. This implies that Mississippi producers were probably better informed in their loss prevention strategies, and spent what was necessary to employ those strategies.

Overall, catfish producers were most likely to contact a WS specialist. The greater proportion catfish producers requesting assistance may be motivated by both actual and perceived losses that are greater than wildlife-caused losses sustained by producers of other commodities. Most of the birds cited to cause losses are diurnal, and the open and expansive catfish ponds result in highly visible losses. Alternatively, mammalian wildlife consumers are more likely to be nocturnal or crepuscular, and the only evidence of depredations are missing commodities. The wildlife-caused losses of catfish may be more difficult to resolve because the depredating species are more frequently migratory birds than resident mammals (Hoy et al. 1989; Stickley and Andrews 1989; Wywialowski 1998). A U.S. Fish and Wildlife Service blanket depredation order should become a final rule in 1998. Hence, aquacultural producers may request WS assistance more frequently both because their loss rates are greater and because the complexity in resolving their problems is greater than for other producers of most other commodities.

New and Innovative Means to Resolve Problems

Only direct wildlife-caused losses were estimated in the earliest surveys, although indirect costs of protecting crops or livestock can be substantial (Pearson and Caroline 1981; Stickley and Andrews 1989; Andelt 1992). Sheep and lamb producers estimated that they spent $1.77 and $0.50/breeding animal on non-lethal and lethal means, respectively, to protect their flocks from wildlife-caused losses in 1994 (Simpson 1995), and 65.5% of sheep producers used some predator management practices in 1994 (USDA 1996). Overall, catfish producers spent $5.4 million protecting their operations from wildlife-caused losses.

The economic benefits to farmers of incorporating wildlife-derived benefits into operations have been demonstrated (Rasker et al. 1991; Butler and Workman 1993). Such wildlife-derived benefits may be most equitably allocated for resident wildlife within predominantly private lands. Equitable distribution of benefits and costs of wildlife becomes more complicated with seasonally migratory resident wildlife in a mosaic of public and private lands (Arha 1996). Frustrations of producers may be greatest when depredating wildlife are migratory birds as demonstrated by high proportions of producers with losses and high dollar-value losses as expressed by aquacultural producers in this survey. Management that benefits both wildlife and the private landowner becomes more complex with migratory wildlife because the economic benefits of migratory wildlife are unlikely to be distributed to the same people as the costs of sustaining wildlife (Heinrich and Craven 1992). Some means of reallocation between "gainers" and "losers" is both appropriate and socially desirable. Public assistance to alleviate losses is one form of redistributing the benefits and costs of our publicly-owned wildlife resource. Other creative methods to either prevent losses or correct distributional inequities should be sought by the wildlife profession to promote greater harmony between agriculturalists and wildlife enthusiasts.

Some may still argue that this study merely reflects agriculturalists perceptions of loss and does not accurately reflect the real losses. The author contends that data from verified loss studies supports these estimates as consistent with actual losses. Further, if a problem is perceived to exist, a problem exists. If the perception does not reflect reality, the appropriate resolution of the problem may lie in sharing information rather than actual damage reduction, but resolution of the problem is still imperative for wildlife managers (Craven et al. 1992). For individuals with either perceived or real substantial losses, wildlife managers should take actions to lessen their net losses (Heinrich and Craven 1992) or provide information to producers to alleviate their concerns about losses (Craven et al. 1992).

Agricultural producers frequently provide habitat for publicly-owned wildlife. The dependencies between agriculture and environmental enhancements that benefit wildlife have become increasingly apparent in public debate over the farm bills. Support from agriculturalists will be enhanced if their needs and interests are considered in conjunction with wildlife and environmental concerns. Wildlife managers may receive more support for their decisions if they acknowledge the losses that agricultural producers perceive to be caused by wildlife and take appropriate actions to alleviate both real and perceived losses.

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NON-PREDATOR VERTEBRATE PEST DAMAGE IN CALIFORNIA AGRICULTURE: AN ASSESSMENT OF ECONOMIC IMPACTS IN SELECTED CROPS

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ABSTRACT: State-wide economic impacts of non-predator vertebrate pest damage were estimated for all pests causing damage in 19 California commodities. Average field-level damage estimates and vertebrate control costs were collected for each commodity, and across six production regions. Economic impacts were estimated by comparing simulated market outcomes in the absence of vertebrate pest damage with observed market outcomes. This analysis indicates that, for the 19 commodities considered, the economic cost of vertebrate pest damage ranged between $46.9 to $162.8 million during 1995 with a mean estimated impact of $95.9 million.

KEY WORDS: economic impacts, economics, vertebrate pests, wildlife damage

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INTRODUCTION

Vertebrate pests are responsible for significant damage to agricultural production systems in California. The animals causing damage include primarily small rodents, a variety of birds, and a few large mammals. As debate continues regarding whether and how these animals should be managed, agriculturists are operating under an increasingly stringent set of state and federal regulations that prescribe the method, place, and timing of control options. In addition to various types of use restrictions for toxicants, producers must also comply with provisions of the Migratory Bird Treaty Act and the Endangered Species Act, both of which influence when and how vertebrate pests may be controlled, if at all.

Although a number of analysts have estimated the economic impact of vertebrate-pest damage for individual commodities in California, few attempts have been made to quantify the state-wide cost of damage. In an effort to better understand these costs, a project was initiated with funding from the California Department of Food and Agriculture to estimate the economic impact of vertebrate damage in selected California commodities. This paper summarizes the main results of the authors' analysis.

VERTEBRATE PEST PROBLEMS IN CALIFORNIA AGRICULTURE

The list of vertebrate pest problems in California agriculture is potentially a long one. Virtually any living animal may cause significant economic harm if its numbers become large enough, or if its natural habitat becomes sufficiently limited. Indeed, the very classification of an animal as a "pest" is essentially an arbitrary decision that depends on one's perspective. This section briefly reviews the damages caused by a group of vertebrate species for which there is a clear consensus among agriculturists regarding their classification as pests. This does not mean there are not many other vertebrates that often act as pests and that cause significant economic injury, only that the authors have chosen to focus on these particular pests to keep the scope of their analysis within reasonable limits. For a more complete listing and discussion of vertebrate pest problems in California, see California Department of Food and Agriculture (1994).

Small Mammals

Rodents and jackrabbits account for a large fraction of total vertebrate pest damages and cause similar types of problems. They are destructive to vine and root systems, eat or otherwise destroy many vegetable, field, hay, and nut crops, and create burrow systems that can be destructive to crop growth and cause problems with mechanical harvesting operations. Ground squirrel and gopher problems are particularly widespread, and are considered the two most important vertebrate pests throughout the state. Although yield losses due to these animals are generally controllable in most crops and rarely exceed 2% or 3%, this is not always the case. For example, according to one University of California scientist, the Beldings ground squirrel is capable of causing yield losses of over 20% in alfalfa grown in the northeastern portion of the state, mainly because there are currently no effective controls available (Whisson 1997).

Meadow mice or voles are also important in many crops, and because they are capable of rapid reproduction, require careful monitoring. An industry source estimates current yield losses in most artichoke fields of the central coast to be 10 to 15% in a best-case scenario, with most growers spending between $80 to $100 per acre on control measures (Puck 1997). Voles also represent a significant problem in overwintered sugar beets according to Salmon, et al. (1984) who reported a 9% loss in total production on a 111 hectare commercial sugar beet field located in Northern California. A number of rats, especially the Norway rat, cause significant damage in orchards, and also transmit disease in dairy and poultry operations. Jackrabbits are also considered an important agricultural pest.

There is significant year-to-year variability in the damage created by small mammals due not only to variation in climatic conditions, but also to the degree of care taken in practicing control. Thus, although severe crop damage can generally be avoided, lack of appropriate control can lead to nearly complete crop loss in some cases. Another important source of heterogeneity in pest damage is geography. For example, Salmon (1987), using detailed rodenticide-use data from Tulare County, notes that the number of acres treated with rodenticides varies from 0.3 to 69.9% of total planted acres across 26 crops. If we suppose that treatment generally occurs where pest problems are most severe, these figures highlight the fact that pest damage varies considerably depending on location.

Most vertebrate control specialists view rodent control as preventive in nature. That is, if a little care is taken in ensuring that rodent populations are kept under control, then most, if not all, damage can be avoided. Although there are a number of non-chemical methods available for rodent control, most specialists see chemical methods as superior both in terms of cost and effectiveness. Toxicants used for control of rodents and jackrabbits include anticoagulants (chlorophacinone and diphacinone), zinc phosphide, strychnine, and fumigants (aluminum phosphide and gas cartridges). Although trapping can be effective under some circumstances, it is generally considered too time consuming and impractical with large populations. Ground squirrels, meadow mice, and rats are primarily controlled with anticoagulants or zinc phosphide, pocket gophers with strychnine, and rabbits with anticoagulants, trapping, shooting, and exclusion.

Large Mammals

Although most large mammals are known for their predatory behavior, some are also a nuisance in cropland. For example, coyotes often destroy plastic irrigation pipe in orchard and vineyard operations, which can disrupt irrigation timing and require costly, time-consuming repair efforts. One vineyard operator in Monterey County estimated a total annual cost of $3,503 for repair of coyote-damaged drip irrigation equipment on 378 acres, representing a cost of nearly $10 per acre (Scaroni 1997). Coyotes also cause significant harm to watermelon producers through destruction of the ripened fruit. Feral pigs are another important non-predator pest. They create damage to field crops through rooting and crop consumption, and destroy or foul feed and water sources in livestock operations. Both of these animals are generally controlled with hunting or trapping methods. In California, it is not uncommon for ranchers to promote private hunting of pigs on their land, and in some cases to even sell hunting rights.

Birds

Birds cause a wide variety of problems throughout California, and are generally difficult to control. Birds cause the greatest damage in fruit and nut crops, and in emerging crops, particularly lettuce. Damage to pistachio and almond orchards in the Central Valley have been well documented (Salmon, et al. 1986; Hassey and Salmon 1993), as well as to wild rice operations in Northern California (Gorenzel, et al. 1990). Bird damage in vineyards is also significant, and more important in table grapes because damaged fruit does not store well. The birds causing the greatest damage include the horned lark, crowned sparrow, house finch, blackbird, starling, and crow. Of these, only starlings may be controlled without restriction or some form of supervision by either the County Agricultural Commissioner (CAC), or the U.S. Fish and Wildlife Service (California Department of Food and Agriculture 1994). Generally, state and federal restrictions governing bird control are more widespread than with rodents and other vertebrate pests. In most situations, growers use a combination of sound and other scare tactics, trapping, and in some cases, shooting.

In many commodities, two or more of the pests described above may simultaneously cause damage. In the discussion of methods and results that follows, the authors measure the cumulative impact of each pest for each commodity.

METHODS

Data

The first step in the authors' analysis involved an extensive search of existing literature relating to wildlife damage in California. While numerous technical papers describing the efficacy of alternative pest-control options were found and reviewed, comparatively little attention has been focused in past research on the economics of vertebrate-pest control. Likewise, descriptive information on the incidence and severity of pest damage across the state was found to be extremely limited. Table 1 summarizes past studies used in this analysis.

Following a review of published literature, interviews were conducted with over 70 individuals who have knowledge of vertebrate-pest issues in California. The interviewees included university scientists, farm advisors, County Agricultural Commissioner (CAC) personnel, growers, and private pest-control advisors. A combination of descriptive and empirical information was collected through these interviews, with the questions tailored to the respondent and to his or her particular expertise.

Although reliance on expert opinion has well recognized limitations, it would be impossible to develop a statewide picture of impacts any other way. Furthermore, the authors incorporate uncertainty regarding expected impacts by specifying ranges for each of the key parameters in their impact model. This allows the authors to develop estimates of economic impact that reflect both uncertainty by experts regarding the level of damages in an average year, and variation in damages caused by unpredictable climatic and environmental factors. Table 2 presents average values for each of the key parameters used in the model. Also specified are low and high estimates for each parameter, and these were used to generate ranges of economic impacts as described below.

Based on initial data collection efforts, 19 crops were selected for which vertebrate-pest problems appeared to be particularly severe. For each crop, between two and seven key production regions were identified, paying particular attention to differences in the nature and severity of vertebrate-pest problems across each of the regions. Data from 1995 on harvested acreage, production, and average price were then collected for each crop/region combination from the California Department of Food and Agriculture. These data represented the base, or *status quo*, situation from which economic impacts were estimated.

Table 1. Published estimates of vertebrate damage in California.

Source	Crop(s) Considered	Summary of results
Crabb, Salmon, and Marsh	Pistachios	Reports 2 to 10% yield loss on 77% of state's acres. Estimated $1.8 million total loss.
Gorenzel and Salmon	Peaches and Prunes	Two case studies of gopher and rabbit damage in central valley orchards (Sutter and Fresno counties). Present discounted value of losses between $9,822 to $27,703 on 39 acres for prunes, and between $700 to $1,589 on 19 acres in peaches. These losses excluded rodent control costs.
Gorenzel, Marcum, and Salmon	Wild Rice	Reports at least a 5% yield loss after controls have been applied, and $85/acre control cost for control with highest benefit-cost ratio.
Hasey and Salmon	Almonds	3 to 4% crop loss from birds, mainly crows, in affected areas of northern California. Growers experiencing loss expressed willingness to pay on average $25/acre to reduce damage by 50%.
Salmon, Gorenzel, and Lickliter	Sugar Beets	Reports 9% crop loss in overwintered beets in northern California where no controls are applied.

Table 2. Average parameter values used in market simulation.

Crop	Yield Damage	Per-Acre Control Cost	% Acres Affected	Supply Elasticity	Demand Elasticity
Alfalfa	7.83	5	17	0.85	-1.30
Almonds	3.50	20	30	0.23	-0.57
Artichokes	15.00	90	70	0.46	-0.70
Carrots	0.62	5	40	0.80	-0.75
Cauliflower	0.50	5	40	0.80	-0.55
Citrus, Lemons	3.50	10	30	0.23	-0.41
Citrus, Other	0.50	5	30	0.23	-0.41
Grapes, Other	1.02	11	40	0.23	-0.35
Grapes, Table	3.50	26	40	0.23	-0.44
Lettuce	3.75	24	40	0.80	-0.75
Pistachios	5.75	20	40	0.23	-0.74
Potatoes	1.38	5	28	0.47	-0.22
Stone Fruits[1]	0.68	10	30	0.23	-0.47
Strawberries	1.28	10	40	0.53	-0.60
Sugar Beets	2.44	5	40	0.36	-0.42
Tomatoes, Fr.	1.38	5	30	0.85	-0.97
Tomatoes, Pr.	0.50	40	30	0.85	-0.97
Walnuts	2.88	14	40	0.23	-0.69
Watermelon	1.38	10	30	0.80	-0.53
Wheat	1.38	6	40	0.85	-1.30

[1]Includes apricots, cherries, nectarines, peaches, and plums.
Source: References in Table 1, and interviews with USDA, CAC, CDFA, industry, and university sources.

Measuring Gains and Losses

The methodology used for estimating impacts follows that developed in Lichtenberg et al. (1988), Zilberman (1991), and Hueth et al. (1998). This methodology integrates estimates of yield damage and per-acre control costs with market data to simulate shifts in production that would occur in the absence of pest damage, and the resulting changes in prices of agricultural commodities. With estimated changes in production and prices, economic impacts or changes in economic welfare were then calculated.[1] The authors incorporate uncertainty with regard to the underlying parameters in their model by simulating impacts under 1,000 different configurations of parameter values.

Economic welfare is defined as the sum of consumer and producer surplus, and producers are divided into two categories: those whose acres are affected by vertebrate pests, and those whose acres are unaffected. Consumer surplus measures the difference between the benefits derived from a certain level of consumption and the cost at the market, and producer surplus is simply a measure of producer profit. The total economic impact of vertebrate pest damage is then calculated as the difference between total economic welfare in the absence of vertebrate pest damage, and total economic welfare in the *status quo*.

The existence of vertebrate damage reduces total output and, therefore, results in higher market prices for agricultural commodities than would occur in the absence of damage. This represents an unambiguous loss to consumers who end up paying higher prices for food commodities, however, the implications for producers are less clear. Producers growing in areas unaffected by vertebrate damage unambiguously gain, because they receive a higher price for their produce than they would if all production regions were immune from damage. The remaining producers may gain or lose depending on how much prices rise. As production falls, producers in affected areas lose from the sale of less output, but also may gain since they are paid a higher price on each unit sold. The net effect on revenue is indeterminate, and depends on the extent to which market price responds to a decrease in output (i.e., on the price elasticity of demand), on the extent of yield damage, and on the level of vertebrate-control costs. If demand is price inelastic, then even a small reduction in quantity can have a large impact on market price. In this case, producers in affected areas can gain as a result of a contraction in their output.

Although somewhat counterintuitive, this observation is consistent with the practice in some agricultural industries to use supply control in order to "maintain stable prices." The difference here is that many growers are practicing supply control *involuntarily,* and furthermore, are not receiving any compensation for lost product. Thus, although vertebrate damage in some ways achieves an outcome similar to that of an explicit supply-control program, the distributional consequences of the supply control are very different. In particular, one segment of the industry—growers whose acres are unaffected by vertebrate damage—gain at the expense of another segment. The estimates of economic impact presented in the next section confirm these points.

[1]Space limitations preclude inclusion of the full model, however, details may be obtained upon request from the authors.

RESULTS

Table 3 presents impacts for each crop, aggregating across regions, and Table 4 presents producer impacts for growers in affected and unaffected regions. All estimates represent mean impacts, unless otherwise indicated. The first column in Table 3 reports the percentage increase in price resulting from vertebrate damage. The highest and lowest price rises are for artichokes (9.36%), and wheat (0.09%). This reflects significant yield damage and California's dominant position relative to the rest of the country in the case of artichokes, and moderate damage together with the relatively minor importance of California wheat in national and world wheat markets, in the case of wheat.

The next two columns contain losses to all producers, both those affected and unaffected by vertebrate damage, and to consumers. The negative values in the producer-loss column indicate that, in aggregate, producers generally gain from vertebrate damage. This occurs for two reasons: first, demand for most agricultural commodities is inelastic, meaning that a small reduction in supply increases price significantly. Thus, for growers in affected regions, the cost of vertebrate damage in terms of lost production and control expenditures are somewhat offset by higher prices. Second, growers in unaffected areas benefit directly from higher prices. The results in Table 3 indicate that, added across both groups, producers experience a net gain. The total gain to producers from vertebrate pest damage is estimated to be $17.9 million in a typical year, while consumers lose approximately $113.8 million.

The final three columns report total welfare loss, representing the sum of producer and consumer losses. Recall from the previous section that economic impacts for each crop were computed one thousand times, with each iteration representing a different configuration of parameter values. Thus, the first total-welfare loss column reports x which is defined as the number such that 5% of simulated outcomes lie below x. Similarly, the next column reports y which is defined as the number such that 5% of all simulations lie above y. The final column contains the mean total welfare loss. Thus, in 1,000 simulations, 5% of the estimated total welfare loss calculations were smaller than $46.9 million, 5% were greater than $162.8 million, and on average were estimated at $95.9 million. This variability highlights the significant uncertainty associated with the underlying parameters of the analysis. Table 3 is also useful for comparing losses across commodity groups. Damage in vegetable crops is responsible for the largest component of total economic impact with average losses of $32.4 million. Fruits, nuts, and field crops then follow with total impacts of $25.2 million, $21.0 million, and $17.2 million, respectively.

An important drawback of reporting aggregate losses as in Table 3 is that doing so ignores the fact that growers who gain as a result of pest damage, do so at the expense

Table 3. Summary of economic impacts by crop.

Crop	Price Change (percent) ($1,000)	Producer Loss ($1,000)	Consumer Loss ($1,000)	Total Welfare Loss λ=0.05 ($1,000)	Total Welfare Loss λ=0.95 ($1,000)	Total Welfare Loss Average ($1,000)
Vegetables						
Artichokes	9.36	-1,031	6,339	3,698	7,086	5,309
Carrots	0.32	-88	1,022	193	1,430	934
Lettuce	1.90	-1,902	17,306	7,144	27,405	15,403
Tomatoes, Fr.	0.64	-261	2,106	837	3,672	1,845
Tomatoes, Pr.	1.07	1,233	7,660	5,785	13,155	8,893
Total		-2,049	34,433	17,657	52,748	32,384
Fruits						
Apricots	0.46	-224	622	196	768	398
Cherries	0.58	-327	780	196	939	453
Citrus, Lemon	1.16	-1,972	4,278	930	4,203	2,306
Citrus, Other	0.31	-398	1,427	463	1,586	1,029
Grapes, Other	0.48	-4,429	13,195	3,113	15,141	8,765
Grapes, Table	1.57	-6,154	13,794	2,984	14,012	7,640
Nectarines	0.62	-192	644	180	937	453
Peaches	0.62	-700	2,006	639	2,499	1,307
Plums	0.66	-74	389	136	604	315
Strawberries	0.75	-1,209	3,783	284	6,138	2,574
Total		-15,679	40,918	9,121	46,827	25,240
Nuts						
Almonds	0.97	-4,082	17,596	5,678	23,425	13,515
Pistachios	2.10	-501	3,831	744	6,769	3,329
Walnuts	1.13	-565	4,747	1,869	8,313	4,182
Total		-5,148	26,174	8,291	38,507	21,026
Field Crops						
Alfalfa	1.21	3,401	9,803	9,348	18,702	13,204
Potatoes	0.55	-157	497	174	488	340
Sugar Beets	0.61	-503	1,796	779	1,987	1,293
Wheat	0.09	2,238	172	1,502	3,530	2,410
Total		4,979	12,268	11,803	24,707	17,247
Grand Total		-17,897	113,793	46,872	162,789	95,897

Source: Calculated.

Table 4. Producer impacts.

Crop	Producer Surplus Change: Affected Areas (1) ($1,000)	Producer Surplus Change: Unaffected Areas (2) ($1,000)	Producer Loss/Revenue in Affected Areas	Total (1)+(2) ($1,000)
Vegetables				
Artichokes	-1,049	2,079	3.27	1,030
Carrots	-527	615	0.41	88
Lettuce	-8,684	10,586	2.45	1,902
Tomatoes	-6,903	5,930	1.36	-970
Total	-17,163	19,210		2,050
Fruits				
Citrus	-709	1,090	1.72	358
Grapes, Other	-2,225	8,379	1.19	7,640
Grapes, Table	-3,519	7,949	0.87	4,430
Strawberries	1,073	2,281	0.54	1,208
Total	-5,380	19,699		13,636
Nuts				
Almonds	-8,359	12,440	2.78	4,081
Pistachios	-1,853	2,354	4.74	501
Walnuts	-2,310	2,877	2.82	567
Total	-8,816	17,671		5,149
Field Crops				
Alfalfa	-8,880	5,894	7.75	-2,986
Potatoes	-143	299	0.39	156
Sugar Beets	-581	1,083	1.44	502
Wheat	-2,342	102	3.62	-2,240
Total	-11,946	7,378	3.30	-4,568
Grand Total	-43,305	63,958		16,267

Source: Calculated.

of affected growers. Table 4 highlights this fact. The first two columns report losses to growers in affected and unaffected regions, respectively. The next column reports losses as a fraction of total grower revenue for growers in affected regions, and the final column reports total grower losses. For example, artichoke growers as a whole likely gain from vertebrate damage, but this hides the fact that growers in affected regions lose over $17 million annually, while growers in unaffected areas gain over $19 million annually.

Also from Table 4, strawberry growers in both affected and unaffected areas gain from vertebrate damage. This occurs because average yield damage and control costs are fairly low, while the demand for strawberries is fairly inelastic. In contrast, although wheat growers in California also experience fairly light damage, there is nevertheless a significant cost. This occurs because the demand for California wheat is very elastic, so that even a large change in the total supply of California wheat will have little or no influence on the price received by the state's growers. As a fraction of grower revenue, losses in artichokes and alfalfa are highest. Profit margins are tight for most agricultural enterprises, and losing 3 to 5% of gross revenue can be critical. Lettuce, nut crops, sugar beets, and wheat also experience significant damage as a fraction of grower revenue.

CONCLUSION AND DISCUSSION

This study estimates the economic impact of non-predator vertebrate pest damage in 19 California crops. Measuring the economic impact from vertebrate pest damage at the state level is complicated by the fact that existing evidence on crop damage at the field level is scarce, and because field-level damages vary considerably across crops and regions. The authors' analysis disaggregates impacts across these dimensions to convey the localized nature of vertebrate damages, and also presents a range of impacts that are meant to convey uncertainty associated with the underlying parameters of their model.

Overall, their estimates indicate that the economic impact from vertebrate pest damage lies between $46.8 million to $162.8 million, with a mean estimated impact of $95.9 million. These results represent a lower bound on the total impacts of vertebrate damage in California because only a subset of all agricultural activity in the state was considered. Furthermore, there are many agriculture-related vertebrate pest problems that are not considered. For example, burrowing rodents create significant damage in irrigation canals, and some agricultural pests serve as sources of disease transmission to urban areas. Also, aggregate impacts hide the often crop- and location-specific nature of vertebrate damage. Finally, the impacts reported in this study do not address the potential impact of vertebrate pest damage with further restrictions or in the absence of existing controls.

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HUMANE SOCIETY: GOOD GUYS OR GESTAPO?

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ABSTRACT: Humane Societies and Societies for the Prevention of Cruelty to Animals perform important functions for the state, the counties, the community, and the public in protecting animal rights and enforcing state animal laws. Their staffs are hardworking and well meaning, but are not trained in police work. As the Societies have the right to conduct searches, seize property, make arrests, and use deadly force, they are required by the Constitution to perform such functions only after they have shown probable cause to a neutral party and obtained a warrant. Their failure to obtain warrants before performing such intrusive functions violates trappers' and homeowners' civil rights which subjects the Societies to suits for damages. To truly protect the public and to protect their budgets, the Societies should train their staff in civil rights and procedures. The Societies have the powers of the police, but resist following the laws and rules that apply to the exercise of police powers. In their zeal to protect animals, they have invaded people's property, even their houses, confiscated traps and released animals—all without warrants or other review of their actions. These actions have led to the question of whether the Societies are "Good Guys or the Gestapo?"

KEY WORDS: Humane Societies, Societies for the Prevention of Cruelty to Animals, civil rights, police powers, constitution, Fourth Amendment, due process, lawsuits, damages, searches and seizures, arrests, trappers

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INTRODUCTION

The Humane Society is a private organization that has been given significant powers by the state to prevent and to enforce the state law concerning cruelty to animals. The Humane Societies see themselves as animal protection organizations to foster respect, understanding, and compassion for all creatures. In many California counties, the Humane Societies or Societies for the Prevention of Cruelty to Animals, which are referred jointly to as "Society" for the balance of this paper, fulfill the functions of the animal control officer under contract to the county.

The thesis of this paper is that while the Societies see themselves as compassionate, caring "good guys," they lack respect and understanding of basic rights protected by the Fourth Amendment to the United States Constitution and the California Constitution. There is no doubt that the Societies mean well and do important work in the area of animal control; however, no matter how much good work they do, it cannot justify their violations of the civil rights of trappers and their customers. The right of a citizen to be secure in his or her home is one of the most fundamental rights protected by the United States Constitution and the Bill of Rights. This right, which includes the right to not be subjected to warrantless searches and seizures and to not be subjected to warrantless arrests, is routinely violated by the Society and its compassionate and well-meaning, but overzealous, staff who trample onto private property, invade homes, seize traps, and arrest people—all without warrants. In some of cases the author has seen, the Society staff have acted like storm troopers trampling the rights of citizens in their efforts to protect animals, giving rise to the question, "Is the Humane Society a Good Guy or Gestapo?"

HUMANE SOCIETIES HAVE STATE POLICE POWERS

Societies are private organizations that have no inherent power, but derive all their powers and authority to enforce animal laws from the State. As in most states, in California, the counties can chose to operate their own animal control services or to hire the Society to perform animals control services for the county.

Officers of Societies ("Humane Officers") are given powers of a policeman to enforce the animals laws and to arrest people who violate the laws. California Law (Civil Code § 607) states that a Humane Officer is not a peace officer, but may exercise the powers of a peace officer at all places within the state in order to prevent the perpetration of any act of cruelty upon any animal. To that end, a Humane Officer may summon to his or her aid any bystander. A Humane Officer may make arrests for the violation of any penal law of this state relating to or affecting animals in the same manner as any peace officer. A Humane Officer may also serve search warrants and is authorized to carry firearms while exercising the duties of a Humane Officer. A Humane Officer may even use reasonable force, and deadly force, to prevent the perpetration of any act of cruelty upon any animal (Civil Code § 607).

FEDERAL AND STATE CIVIL RIGHTS LAWS LIMIT THE SOCIETIES POWERS AND METHODS; THEY HAVE TO GET SEARCH WARRANTS AND GIVE MIRANDA WARNINGS JUST LIKE THE POLICE DO

While ordinarily one does not think of the Humane Society, animal control staff, or the "dog catcher" as subject to civil rights laws, they are because they are acting under the "color of state law" with the powers to seize property, search, and make arrests. Just as police powers are limited in the manner and procedures used to collect evidence, conduct searches, make seizures, and effectuate arrests, when Societies are fulfilling police-like functions, they are governed by the same civil rights laws, rules, and procedures. To understand the limitations that the civil rights laws put on the Societies, a review of the civil rights laws is necessary.

The Federal Civil Rights Statute (42 U.S.C. § 1983, "Section 1983") states:

> Every person who, under color of any statute, ordinance, regulation, custom, or usage, of any State . . . subjects, or causes to be subjected, any citizen of the United States or other persons within the jurisdiction thereof to the deprivation of any rights, privileges, or immunities secured by the Constitution and laws, shall be liable to the party injured in an action at law, suit in equity, or other proper proceeding for redress.

Section 1983 has two essential elements: "[1] the conduct complained of must have been committed by a person acting under color of state law; and [2] must result in a deprivation of rights, privileges, or immunities secured by the Constitution or laws of the United States" (Bendiburg v. Dempsey 1990). Each of these elements will be discussed in the following sections.

THE SOCIETIES ACT UNDER COLOR OF STATE LAW

By delegating significant state power to the Societies, including the right to enforce laws, serve warrants, and make arrests, the state effectively deputized the Societies, rendering them state actors under Section 1983. "Actions of private individuals performing state functions are subject to the Fourteenth Amendment" (Amalgamated Food Employees Union v. Logan Valley Plaza 1968). The Societies perform the state function of enforcing animal control laws pursuant to a state law, and the state has granted Society officers with peace officer authority to arrest, wear uniforms and badges, carry guns, and use deadly force. Clearly, the Societies are operating under the color of state law.

The situation is no different than if a city contracted with a private firm to provide a police force. No one would argue that a city police officer who worked for a private company under contract to a city, instead of directly for the city, would be able to search without warrants, arrest without probable cause, or interrogate in back rooms with a rubber hose, all without judicial controls. The same reasoning applies to the Societies: their "private" status does not exempt them from civil rights laws when they are performing governmental functions.

The California courts have routinely held that Societies' actions are state action under the civil rights laws. In a recent case, the court said: "This appeal presents the question of whether animal control officers can lawfully enter a home, absent a warrant or consent, to seize and impound a homeowner's dog for a violation of the leash law. We hold that the Fourth Amendment to the United States Constitution precludes such conduct." (Conway v. Pasadena Humane Society 1996).

SEARCHES, SEIZURES OF TRAPS, AND ARRESTS BY THE SOCIETIES MAY VIOLATE CITIZEN'S CIVIL RIGHTS

Since the Societies are operating under the color of state law, the Constitutional Bill of Rights applies to their actions, which means if they violate the rights, privileges, or immunities secured by the Constitution or laws of the United States, they are liable under the civil rights laws. The question is then, "What types of activities may give rise to a violation of rights?"

Warrantless Searches

Humane Officers routinely enter backyards to investigate hurt or sick animals, and to release animals from traps. Such entries are almost always done without warrants or without permission from the homeowner. California law has held that absent prior permission, Societies cannot conduct a warrantless search and seizure. In Pasadena, a Society officer was chasing an injured dog and the dog ran into a house through the dog door. The officer was concerned about the dog, so he tried the door and when he found it unlocked, he went into the house—all without a warrant. The homeowner found out about the invasion, sued, and the court, not surprisingly, held that the statutes upon which the Society relied did not dispense with the Fourth Amendment requirement that official entry into a home be justified by warrant, consent, or exigent circumstances. "A statute does not trump the Constitution" (Conway v. Pasadena Humane Society), which means the law creating the Societies can not give them any more power than the Constitution allows.

Warrantless Seizures

Societies seize traps when they believe that they are either illegal traps, improperly marked, or contain distressed animals. These seizures are routinely done without warrants and without prior notice to the trapper. In one case with which the author's firm was involved, the Society was in a dispute with a trapper over tagging of his traps. On numerous occasions, the Society seized his traps and released the animals. The Society claimed that it seized the traps because they were unidentified, but when the trapper demanded the return of the traps, the Society argued that all of his traps were returned. Asked the simple question, "If you seized the traps because you could not tell who they belonged to, how did you know they were returned?"—they had no answers. In fact, if the traps were seized because they were unmarked, how could the Society have returned any of them? The real problem is that the seizure of the trapper's property without notice or a warrant is a clear violation of the Fourth Amendment prohibitions against warrantless seizures.

Releases

Societies believe that they have a duty to release animals from any trap, legal or illegal, if the animal is suffering, a definition which includes wet animals. (Does a wet raccoon fair better in the rain than when it is in a trap?) To perform a release, the Humane Officer must conduct a search of the homeowner's property, then seize, at least temporarily, the trapper's property (the trap), and then release what is arguably the trapper's property, the animal. The loss of the animal adversely affects the trapper's business because he or she does not get paid, which means a property right is involved. The releases, if done without a warrant, violate trappers' rights.

THE EXCEPTIONS TO WARRANT REQUIREMENTS DO NOT APPLY IN SOCIETY FUNCTIONS SO THEY NEED TO GET WARRANTS OR PERMISSION IN ALL CASES

Probable Cause Is Not an Excuse for Not Getting a Warrant

Often the Societies' initial justification for warrantless searches is "probable cause," which demonstrates that the Societies are clueless regarding the Fourth Amendment and violations of civil rights. In one case, the Society justified its warrantless searches as follows: "In each case, because the officers had reason to believe that criminality may be afoot, they were justified in entering onto the property in question to investigate the complaints they received."

The problem with this justification is that probable cause is not a justification for a warrantless search; it is a necessary ingredient to obtaining a warrant. "Reasonable or probable cause to suspect or believe that contraband is present or that a crime is being committed or attempted must exist to justify a search pursuant to a search warrant" (Shvey v. Superior Court of Los Angeles County 1973).

The Societies' standard for warrantless searches as stated above does not even meet the test for probable cause for obtaining a warrant, which is "such a state of facts as would lead a person of ordinary care and prudence to believe, or entertain an honest and strong suspicion that the person involved is guilty of the offense charged" (People v. Kilvington 1894). A belief is not a set of facts, because a belief is, by definition, based on unverifiable feelings. That "criminality may be afoot" falls far short of the requirement that the government has a good faith belief that a crime is being committed. The Societies' position that they can conduct warrantless searches based on a "belief" that criminality "may be afoot" is beyond chilling, indeed, it is scary. Think about big brother busting into your house anytime it says it "believes that criminality may be afoot."

Wet Or Even Suffering Animals Are Not Exigent Circumstances

Societies also try to justify their warrantless searches and seizures based on the "exigent circumstances" exception, but exigent circumstances are true emergencies such as police searches where a fire has broken out and they have to enter before a warrant could be obtained, not mere conveniences or concerns by Society staff. Some Societies argue that any time an animal is being mistreated, the Society can conduct warrantless searches and seizures under a emergency or exigent circumstance doctrine, but a suffering animal does not rise to the level of emergency required to justify civil rights violations.

Warrantless searches have been recognized in emergency situations requiring swift action to prevent imminent danger to life and limb, such as where the police were investigating a conspiracy to kill a presidential candidate such as Robert Kennedy (People v. Sirhan 1972), to prevent serious damage to property (People v. Remiro 1979), or where the police were at the door and heard moaning sounds as if a person were in distress (People v. Roberts 1956). Exigent circumstances also include hot pursuit of a fleeing felon (People v. Escudero 1979), but there are no cases which allow warrantless searches for fleeing, or even suffering, animals.

In a feeble attempt to justify its warrantless searches under an exigent circumstances exception, one Society tried to justify its warrantless searches by claiming that traps were close to the public sidewalk creating an imminent danger to small children and other passersby. The court rejected that argument not only because the emergency did not rise to the "exigent circumstances" level, but because it is not the Societies' responsibility to protect passersby from traps. This example shows the Societies' tendencies to operate outside of the law, perhaps out of frustration at the lack of action by the police, who have to get warrants and comply with civil rights laws.

The Plain View Exception Is Not an Excuse for Illegally Entering Onto Property; It Applies Only to What is Really in Plain View

"Plain view" is an exception to the Fourth Amendment which has four elements. If the police: 1) are legitimately on the property; 2) discover evidence; 3) see such evidence in plain view; and 4) have cause to believe the item is evidence of a crime, then they may seize the evidence without first obtaining a warrant.

In one case, the Humane Officer was told by the homeowner that he was trespassing and ordered him off the property. The officer left, but came back an hour later, decided that the fact the homeowner was not at home justified his entry onto the property, even though it was contrary to the homeowner's express instructions an hour before. In his zeal to release the raccoon, he trespassed on the property without a warrant. To compound the initial illegal entry, he repeated this action an hour later and released another raccoon. In another incident, the Humane Officers left a message on the homeowners' answering machine advising them that the Society had reports of suffering animals, so they entered the property and confiscated traps and released animals. In both incidents, the Society justified its warrantless search based on the plain view doctrine. As none of the officers had the consent of the homeowners to be on the property, the Humane Officers were not legitimately on the premises, and the first leg of the plain view doctrine is not met.

It is the author's view that the second leg of the plain view doctrine is rarely met because in most of the trap-related incidents, the evidence is not in plain view. The plain view exception allows police officers to observe things only in plain sight which means open and visible to the naked eye (People v. Nichols 1970). The plain sight test does not extend to situations where something was easily reached though it was out of sight. For instance, it is not a legal search for a police officer to reach into a recessed area between the bumper and the body of an automobile even though the bumper and the car are in plain view (People v. Conley 1971).

Many of the Society seizures were done at night, because that is when the pests are trapped and start screaming, prompting the neighbors to call the Society. At night it would be virtually impossible to plainly see that a trap is illegal, unless it was an obvious leghold or similar trap. In the case being discussed here, the Society was seizing the traps because under the theory they believed the traps were not properly tagged. It was successfully argued that at night it would be impossible for the Humane Officers to determine whether the traps contained the correct tag, or even if they contained a tag at all, without a search, which was above and beyond what the officers could see in plain view. Similar arguments apply to traps under houses.

The most important aspect of the plain view exception is that the government cannot stand it on its head, and use the fact that they saw something illegal as the basis to invade the property. They have to be legally on the property before the plain view doctrine can be considered. For example, if the homeowner gives permission to search and then the Humane Officers see an illegal trap, that would be under the exception.

Just Because Traps Are in the Open Does Not Mean There Is No Expectation of Privacy

Another theory advanced by the Societies is that no warrant is needed to enter onto private property to seize traps because they are in open fields. If the traps were placed in a field or other area where there would be no expectation of privacy, then the police, a Society, or a passerby could seize them without a warrant, because the trapper had surrendered his rights in the traps. However, traps are not placed in open fields because no one cares about pests in open fields; homeowners and business owners hire trappers. Traps are placed on customers' property adjacent to their houses, or under houses, because that is where the pests live. Whether the traps are under the house, adjacent to the house, or scattered throughout the backyard, clearly they are within the protected zone of privacy, which in England 500 years ago was referred to as the curtilage of the house.

> At common law, the curtilage is the area to which extends the intimate activity associated with the sanctity of a person's home and the privacies of life; the protection afforded the curtilage under the Fourth Amendment is essentially a protection of the families and the personal privacy of an area immediately linked to the home both physically and psychologically where the privacy expectations of most heightened . . . (California v. Ciraolo 1986).

No one would argue that the police could conduct a warrantless search and seizure in a backyard because the owner had no expectation of privacy, but Societies routinely make this argument to justify their trespasses.

Homeowners Cannot Give Permission to Seize Traps

To justify their actions, some Societies have argued that the trappers lend the traps to their customers; therefore, trappers have no right of privacy or reason to object to the taking by the Societies. This argument is contrary to good sense. A trapper's customers hire him to trap and dispose of animals, and, to do so, he must maintain control of the traps. A trapper is obligated by the law to protect the animals in the traps from the elements and to ensure that they have water and food so they do not suffer. Lastly, his clients pay him to take the animals away and dispose of them, and the law requires him to dispose of them in a humane manner. To comply with these rules, a trapper must maintain control of his traps. After all, a trapper is not running a trap leasing service; he is operating a pest control service.

A Temporary Taking Even for One Day or Only One Hour is Still a Taking

Apparently under the theory that a small violation of civil rights does not count, Societies argue that since the seizures are temporary, there are no violations of the Fourth Amendment. In a case against an animal control officer for return of farm animals which had been seized and impounded for running "at large," the court said that: "Moreover, the fact that the deprivation may be temporary does not alter the need for due process" (Carrera v. Bertaini 1976). Even a temporary taking of property without proper procedures is a violation of civil rights.

TAKING TRAPS WITHOUT A PRE-SEIZURE HEARING IS A PROCEDURAL DUE PROCESS VIOLATION

The United States Constitution guarantees every person "procedural due process," which means that the government must provide notice *and* an opportunity to be heard to a person *before* depriving a person of a property interest. The California Supreme Court has also noted that "the Constitution generally requires that an individual be accorded notice and some form of hearing before he is deprived of a protective or liberty interest" (Kash Enterprises, Inc. v. City of Los Angeles 1977). In Beaudreau v. Superior Court (1975), the court again emphasized a need for a hearing *before* a state actor takes another's property:

> We start with the basic proposition that in every case involving a deprivation of property within the purview of the due process clause, the Constitution requires some form of hearing. Absent extraordinary circumstances justifying resort to summary procedures, this hearing must take place *before* an individual is deprived of a significant property interest.

The Societies fail to give trappers notice and an opportunity to be heard before they seize traps; thus, they deprive trappers of procedural due process. The Societies defend their clearly unconstitutional activities under the theory that Humane Officers are exempt from search and seizure laws and that Humane Officers are given privileges not even held by the police. The due process violation is obvious and patent.

SUMMARY

Societies perform important functions for the State, the counties, the community, and the public. Their staffs are hardworking and well meaning, but are not trained in police work. As the Societies perform police functions of conducting searches, seizing property, making arrests, and using deadly force, they are required by the Constitution to perform such functions only after they have shown probable cause to a neutral party and obtained a warrant. Their failure to obtain warrants before performing such intrusive functions, violates the trappers' and homeowners' civil rights, which subjects the Society to suits for damages. To truly protect the public and to protect their budgets, the Societies should train their staff in civil rights and procedures.

The Societies have the powers of the police, but resist following the laws and rules that apply to the exercise of police powers. In their zeal to protect animals, they have invaded people's property, even their houses, confiscated traps, and released animals—all without warrants or other review of their actions. Unless the Societies reform their methods and comply with the Fourth Amendment, they are going to be known as the Animal Control Gestapo.

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MANIPULATING HABITAT QUALITY TO MANAGE VERTEBRATE PESTS

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ABSTRACT: Wildlife damage management has often emphasized density reduction through lethal means. In addition to facing increasing regulatory and social restrictions, this approach also faces ecological problems; density reduction without a concomitant decrease in carrying capacity may only stimulate density-dependent responses that quickly return population densities to pre-control levels. Consequently, habitat manipulation, either to reduce pest density or to divert the pest away from the commodity, has been pursued as an alternative. Habitat manipulation has proven effective in some circumstances and appears promising in others, but the approach is limited by our ability to identify limiting resources or highly preferred foods that can be manipulated economically and with the desired effect. Further, habitat manipulation is not always a long-term solution, may have unwanted effects on non-target species, and may be ineffective if not viewed on a regional scale. Nonetheless, the approach is promising in certain situations. Further research is needed.

KEY WORDS: vertebrate pest management, habitat modification, habitat quality, carrying capacity, alternate foods

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INTRODUCTION

Wildlife damage management has often relied upon reduction of pest densities, chiefly through the use of toxicants, as a primary means of controlling damage. With increasing regulatory and social restrictions on lethal approaches, greater interest has been paid to manipulating habitat quality as an alternative means of reducing damage. In theory, habitat manipulation has decided advantages over lethal approaches; in practice, however, habitat manipulation has important limitations. The purpose of this paper is to outline the conceptual basis for habitat manipulation as a means of managing vertebrate pests, present examples of instances in which habitat manipulation has been applied or proposed, and assess the potential and limitations of the approach.

ECOLOGICAL CONCEPTS

Carrying Capacity and Density Dependence

Carrying capacity is the natural limit of the density of a population, set by availability of resources in a given habitat (Caughley and Sinclair 1994). Exactly which factors determine this limit is the subject of much debate (Pulliam and Haddad 1994), but habitat quality plays a key role.

Demographic processes such as reproduction and survival often vary according to population density and its relationship to carrying capacity. When density is well below carrying capacity, resource availability per individual is increased, thereby promoting higher survival and reproduction in remaining individuals.

Density reduction to control pest damage typically is implemented without a concomitant reduction in carrying capacity. A density-dependent increase in survival, reproduction, or both often results (Putman 1989); such responses may be dramatic (Knowlton 1972; Parkes 1984; Choquenot 1991). Consequently, density reduction to control pest damage may only stimulate density-dependent responses that quickly return population sizes to pre-control levels. Further, the presence of depopulated habitat may serve as a "dispersal sink" (Lidicker 1975; Dobson 1981) that attracts dispersers from elsewhere, further hastening the return to pre-control population levels (Sullivan 1987). Recovery of vertebrate populations following density reduction can occur remarkably quickly, and numbers may even exceed pre-control levels (reviewed in Van Vuren and Smallwood 1996). Thus, a program of long-term density reduction becomes, in effect, an attempt to drive a negative feedback loop in the wrong direction (Caughley and Sinclair 1994). In theory, manipulating habitat quality provides a long-term solution to this dilemma.

Habitat and Habitat Quality

Habitat is defined as an area with the combination of resources (such as food and cover) and environmental conditions (such as the absence of predators) that promote occupancy by a given species (Morrison et al. 1992). High quality habitat provides resources and conditions that result in relatively high rates of survival and reproduction for long periods. In marginal habitat, resources and conditions may be adequate only for intermittent occupancy. Unsuitable habitat results when one or more essential resources or conditions are lacking (Hansson 1977; Morrison et al. 1992). Habitat provides four basic resources required by most vertebrates: food, cover for protection against predators and environmental extremes such as heat and cold, free water for drinking, and space. In addition, particular species may require more specialized resources such as perch or resting sites.

Habitat manipulation might reduce pest damage in either of two ways. First, carrying capacity, thus pest density, might be reduced by lowering habitat quality. Second, vertebrate pests might be lured away from a commodity by providing alternate, higher quality food resources.

HABITAT MANIPULATION TO REDUCE PEST DENSITY

Cultural practices may inadvertently enhance habitat quality for vertebrates that cause damage (e.g., Fitch

1948; Nicholson and Richmond 1984; Loeb 1990; Licht and Sanchez 1993). Consequently, cultural practices might be modified in ways that reduce habitat quality, and thus pest density. To do so, we must be able to identify habitat resouces or environmental conditions, such as food, cover, or absence of predators, that limit habitat quality for a particular species, then reduce or eliminate these resources or conditions. This approach, however, faces three major problems. First, some vertebrate pests have varied diets and generalized cover requirements, thus these species will be relatively unaffected by habitat modification. Second, our knowledge of habitat components that limit abundance is incomplete for some species. Third, modifications of cultural practices that reduce habitat quality for pests may also reduce the yield of the commodity being protected. An obvious example is where damage is caused by the pest feeding on the commodity; reducing food availability to the pest means reducing production. For this reason, habitat manipulation often targets habitat components besides food. Despite these limitations, habitat manipulation to reduce pest densities has shown promise for a variety of species.

Rodents and Rabbits

Voles (*Microtus* spp.) cause serious damage to a variety of crops, especially orchards. Voles require dense herbaceous vegetation both for food and for cover (Sullivan and Hogue 1987; Tobin and Richmond 1993; Edge et al. 1995). Thus, vole density or activity in orchards can be reduced substantially by decreasing the height of herbaceous vegetation through cultivation (Byers et al. 1976), mowing (Brooks and Struger 1985; Godfrey 1987; Edge et al. 1995), or the use of herbicides (Sullivan and Hogue 1987; Davies and Pepper 1989). The frequency of mowing can be reduced by applying growth retardants to mowed vegetation (Godfrey 1987). Cover is apparently more important to voles than food; voles preferred unmowed vegetation even though mowing resulted in higher quality forage (Brooks and Struger 1985). Voles also respond to vegetation density (Nicholson and Richmond 1984), so Tobin and Richmond (1993) proposed that vole activity might be reduced by planting erect, bunch-type plants that provide poor cover. Prunings, brush, and other debris may provide cover for voles and should be removed (Pagano and Madison 1982; Godfrey 1987).

Pocket gophers damage numerous crops. Like voles, gophers require herbaceous vegetation for food; unlike voles, however, gophers rely primarily on underground tunnels for cover. In situations such as orchards and regenerating forests in which the commodity at risk is not the primary food of gophers, gopher densities and damage can be reduced by removing hercaceous vegetation through the use of herbicides (Keith et al. 1959; Hull 1971; Sullivan and Hogue 1987; Engeman et al. 1995, 1997).

Ground-dwelling squirrels, such as ground squirrels (*Spermophilus* spp.), prairie dogs (*Cynomys* spp.), and woodchucks (*Marmota monax*), all require burrows for cover and feed primarily on herbaceous vegetation. Further, because squirrels often detect predators visually, some species appear to prefer areas with sparse, low-stature vegetation. Destruction of burrows can render habitat unsuitable for squirrels, but burrows must be damaged enough to prevent discovery and repair by immigrants (Klitz 1982; Salmon et al. 1987; Gilson and Salmon 1990). Attempts to reduce habitat quality by managing for dense, tall vegetation have had mixed results; this approach shows potential for black-tailed prairie dogs (*C. ludovicianus*) (Cable and Timm 1988; Licht and Sanchez 1993) but appears ineffective for California ground squirrels (*S. beecheyi*) (Fitzgerald and Marsh 1986). Similarly, the addition of hiding cover for predators had no effect on prairie dog activity (Knowles 1988). Swihart (1990) suggested that woodchuck densities in orchards might be reduced by planting herbaceous species that provide poor quality food for woodchucks.

Arboreal squirrels might be managed by manipulating the trees they depend on for habitat. Red squirrels (*Tamiasciurus hudsonicus*) cause damage to regenerating forests by feeding on the vascular tissues of young trees. Stand thinning in lodgepole pine (*Pinus contorta*) forests reduces red squirrel densities (Sullivan and Moses 1986a; Sullivan et al. 1996) and, if conducted on a sufficiently large scale, reduces feeding damage to young trees as well (Sullivan et al. 1996). Further, because damage is greatest in stands with a dense shrub understory, removing shrubs has the potential for reducing damage (Sullivan et al. 1994).

The canefield rat (*Rattus sordidus*) is a major pest in sugar cane in Australia. Damage can be reduced by leaving crop debris in the fields that inhibits growth of summer grasses, the favored food of cane rats, but only if done on a regional scale (Whisson 1996).

Beavers (*Castor canadensis*) require water for cover, either rivers or ponds of a sufficient depth, or smaller streams that beavers impound by dam-building. Removing the aquatic resource renders a habitat unsuitable for beavers. Breaking a beaver dam, however, is ineffective because the sound of running water stimulates beavers to repair the break (Wood and Woodward 1992; Olson and Hubert 1994). The solution is to install a drain that either does not stimulate the repair response or is constructed so that beavers cannot plug it (Wood and Woodward 1992; Olson and Hubert 1994).

Mountain beavers (*Aplodontia rufa*) are burrowing rodents that cause problems for forest regeneration in the Pacific Northwest. Hacker and Coblentz (1993) found that mountain beavers prefer habitats with woody debris and suggested removal of such debris from reforested areas as a means of reducing habitat quality. Destruction of underground nests to prevent reinvasion, however, appears ineffective (Campbell and Evans 1988).

Species of rabbits and hares vary in their habitat requirements. Snowshoe hares (*Lepus americanus*) prefer habitats with dense vegetative cover, so removal of cover either mechanically or chemically will reduce hare densities (Sullivan and Moses 1986b) or damage (Borrecco 1976) in regenerating forests. The European rabbit (*Oryctolatus cuniculus*) is unusual in that it requires burrows for cover; consequently, burrow destruction is an effective means of making habitat unsuitable for rabbits (Burley 1986; Williams and Moore 1995). Jackrabbits

(*L. californicus*) prefer barley as food, but apparently avoid rye, thus a barley field can be protected from jackrabbit depredation by sowing a strip of rye around the perimeter (Lewis 1946). This approach, however, appears ineffective when jackrabbits are at high densities (Evans et al. 1970).

Large Mammals

Brush and Ehrenfeld (1991), noting that early seral stages of deciduous forests provide excellent habitat for white-tailed deer (*Odocoileus virginianus*), proposed that deer damage to a crop might be reduced by managing adjacent woodlands for late seral stages. Feeding damage to gardens can be reduced by planting species that provide poor quality forage for deer (Coey and Mayer undated). Black bears (*Ursus americanus*) cause serious damage to young conifers by stripping off the bark and consuming the cambium tissue beneath (Giusti 1990; Ziegltrum 1994). Because bears select trees of a specific size and damage often occurs soon after a stand is thinned, altering thinning practices has been proposed as a means of reducing damage (Giusti and Schmidt 1988; Guisti 1990).

Birds

Sunflowers and other crops are damaged by a variety of blackbirds. Depredating blackbirds use cattail vegetation in adjacent marshes for roosting, so damage might be reduced by using herbicides to remove cattails (Linz et al. 1992, 1995, 1996). Homan et al. (1994) suggested that plowing sunflower fields soon after harvest will remove an important food source that could promote greater numbers of depredating blackbirds. In contrast, however, Mott (1975) noted that delaying plowing may protect unharvested crops by attracting birds to alternate food sources, such as grain stubble, in unplowed fields. Because blackbirds prefer ears of corn infested with insects, control of insect populations has the potential for making cornfields less attractive to blackbirds (Woronecki et al. 1981; Okurut-Akol et al. 1990). Blackbirds also are a nuisance when they roost in large numbers in urban areas; tree trimming or stand thinning is effective in reducing roost quality, thereby inducing birds to move elsewhere (Good and Johnson 1976; Lyon and Caccamise 1981; Erdman 1982).

Canada geese (*Branta canadensis*) grazing on lawns have caused problems for golf courses, parks, playing fields, and around homes and buildings. Conover (1991, 1992) suggested planting tough-leaf grass species that are poor quality food for geese, or replacing grass turf with unpalatable ground cover, as a means of reducing habitat quality for geese. Additionally, planting shrubs and hedges around smaller lawns may discourage use because geese prefer to feed in areas free of hiding cover for predators (Conover 1992).

Fish-eating birds cause depredations at fish farms. Suggestions for reducing habitat quality for birds include removal of structures used as perches or modification of pond borders to eliminate the shallow water preferred by wading birds (Parkhurst 1994). Some wading birds, however, apparently can adapt to feeding in deep water (Hoy et al. 1989). The use of fish stocks that are less vulnerable to predation has been suggested to reduce losses (Parkhurst 1994). Also, because fish are more difficult to see and capture in turbid water, increasing turbidity of ponds might reduce food availability for depredating birds. This approach, however, may interfere with fish production, thus it is not suitable for some types of commercial fish (Cezilly 1992). Feral pigeons (*Columba livia*) consume stored grain and are a nuisance in urban areas. Removing food sources such as spilled grain may be helpful in some situations (Williams and Corrigan 1994), but may have limited value because pigeons readily use a variety of foods (Fitzwater 1988). Preventing access to water sources, such as rooftop air conditioners, and rendering perch sites unsuitable or inaccessible are effective in reducing habitat quality for pigeons (Martin and Martin 1982; Fitzwater 1988; Williams and Corrigan 1994).

Ravens (*Corvus corax*) are considered a threat to the desert tortoise (*Gopherus agassizii*), a federally-protected species, because they may prey upon young tortoises (Boarman 1992). Efforts to lower habitat quality for ravens include reducing food resources by covering landfills and removing roadkills from highways, eliminating standing water, and denying ravens access to perch sites by installing spike-like devices on utility poles and fenceposts (Boarman 1992; Alice Karl pers. comm.).

Presence of Predators

The presence or absence of predators influences habitat quality for many species of vertebrates. For mammals, the application of predator odors to simulate predator presence alters local distribution, changes feeding behavior, or in some cases reduces damage caused by a variety of species including house mice (*Mus domesticus*) (Dickman 1992), voles (Sullivan et al. 1988a, 1988b; Jedrzejewski et al. 1993; Parsons and Bondrup-Nielsen 1996), gophers (Sullivan et al. 1988c), woodchucks (Swihart 1991), mountain beavers (Epple et al. 1993; Nolte et al. 1993), hares (Sullivan 1986; Sullivan and Crump 1984, 1986), and mule deer (*Odocoileus hemionus*) (Melchiors and Leslie 1985; Andelt et al. 1991). A response to predator odors, however, is not always observed (Wolff and Davis-Born 1997; Thorson et al. 1998).

For birds, simulation of predator presence through visual models (Conover 1982, 1984, 1985; Hothem and DeHaven 1982) or even a trained falcon (Erickson et al. 1990) has proven effective in reducing damage in certain situations. Some studies employed a kite with the image of a hawk that was flown suspended from a helium balloon (Conover 1982, 1984; Hothem and DeHaven 1982), while others used full-size, realistic models (Conover 1979, 1985). For both the kite and the model, motion is important for eliciting a response from birds (Conover 1979, 1985; Marsh et al. 1992). Efficacy of predator models, however, is limited because birds habituate rather quickly (Conover 1979), and they are ineffective for some species (Conover 1979, 1982).

HABITAT MANIPULATION TO DIVERT PESTS

Much damage by vertebrate pests is caused by the pest feeding on a commodity. Damage might be reduced by providing more desirable food resources that alter foraging behavior, thereby diverting the pest away from the commodity. Decisions made by vertebrates during

This paper has been peer reviewed.

foraging are affected by factors such as the ease with which a food is acquired or eaten, as well as palatability or nutritional content of the food (Krebs and Davies 1993). This approach, however, relies upon the pest discovering and preferring the alternate food, and these processes are not well understood (Perry and Pianka 1997). Further, food may be a limiting resource (e.g., Sullivan 1990); consequently food enhancement, if carried out long enough, might increase carrying capacity for the pest, ultimately leading to an increase in pest density. Nonetheless, short-term enhancement of appropriate food resources has the potential for reducing damage. Two approaches have be proposed: managing for increased availability of natural foods, and provisioning of introduced foods.

Rodents

Rodents cause damage in regenerating forests by eating conifer seeds and seedlings and by consuming cambium tissue. Conifer seed survival can be increased dramatically by distributing alternate foods, especially sunflower seeds, which are highly preferred by seed-eating rodents (Sullivan 1978, 1979; Sullivan and Sullivan 1982). Similarly, distribution of sunflower seeds reduces bark damage by squirrels to conifers (Sullivan 1992; Sullivan and Klenner 1993). Because Douglas fir (*Pseudotsuga menziesii*) seedlings are not the preferred food of mountain beavers, Hacker and Coblentz (1993) proposed that damage to fir seedlings might be reduced by managing for preferred foods such as sword fern (*Polystichum munitum*) and salal (*Gaultheria shallon*). Voles show a preference for soybean oil; accordingly, provisioning of artificial "logs" treated with soybean oil has the potential to reduce damage by voles to trees in orchards (Sullivan and Sullivan 1988).

Large Mammals

Consumption of conifer seedlings by black-tailed deer (*Odocoileus hemionus columbianus*) can be reduced substantially by prompt establishment of native forbs that are preferred by deer (Campbell and Evans 1978). Long (1988) proposed that elk (*Cervus elaphus*), which cause feeding damage to private rangelands, might be drawn away by improving habitat quality on public rangelands through the application of herbicides and fertilizer. Bison (*Bison bison*) in Alaska began feeding in barley fields after wildfire suppression caused a reduction in quality of their winter range; thus, Gipson and McKendrick (1982) suggested that resumption of natural burning might draw bison back to adjacent wildlands. Black bear damage to conifers can be reduced by increasing the availability of alternate foods; provisioning of sugarized wood chips has proven effective (Ziegltrum 1994), and planting of highly palatable forbs has been proposed (Giusti and Schmidt 1988).

Birds

Many wildlife refuges plant crops that provide high quality food in order to attract waterfowl away from surrounding agricultural fields (Cowan 1970). A related approach is the lure crop, where depredating birds are allowed to feed unmolested on a crop purchased from a private landowner, thereby reducing depredations on surrounding fields (Gustad 1979; Fairaizl and Pfeifer 1988). If the lure crop is entirely consumed, grain may be provisioned to hold the birds for a time longer (Gustad 1979). Distribution of whole corn softened in water has been proposed as a means of diverting crows (*Corvus brachyrhynchos*) from consuming corn seedlings in recently planted fields (Johnson 1994). Galah (*Cacatua roseicapilla*) depredation on wheat in Australia was reduced by providing an alternative, more preferred food source nearby (Jarman and McKenzie 1983). Batcheller et al. (1984) proposed that depredation by blue jays (*Cyanocitta cristata*) in pecans might be reduced by managing adjacent forests for mature oaks (*Quercus* spp.) that produce large quantities of acorns, a preferred food of blue jays. Establishing buffer populations of frogs, non-commercial fish, or other alternate foods around fish farms has been suggested to divert fish-eating birds away from aquaculture stocks (Parkhurst 1994; Mott and Boyd 1995).

DISCUSSION

The appeal of habitat manipulation as a means of wildlife damage management is that it is nonlethal, works with rather than against ecological processes, and may provide durable and cost-effective solutions. The approach, however, has limitations. Habitat manipulation to reduce pest density will work only for species for which limiting habitat resources have been identified and that can be modified economically. Habitat manipulation to divert the pest from the commodity relies on identification of a more highly preferred food that can be economically enhanced or provisioned and that reliably attracts the pest. Further, long-term food enhancement could lead to increased pest density.

In addition, habitat manipulation faces limitations that extend beyond the interaction between the pest and its habitat. Habitat manipulation is not always a long-term solution because plant populations that have been altered chemically or mechanically may show the same ability for rapid recovery as do some vertebrate populations. In such cases, habitat treatments will require repeated application. Food enhancement, especially when forage species are seeded, must be done judiciously to preclude the introduction or spread of exotic plants. Because a given habitat supports numerous species besides the pest, habitat manipulation may have unwanted consequences for nontarget species (Howard 1967; Borrecco 1976). For example, destruction of ground squirrel burrows may harm rare species that require these burrows for habitat (Loredo et al. 1996). Finally, habitat manipulation relies on inducing the pest to live or feed elsewhere; consequently, the approach should be viewed on a scale larger than that of the individual farm, golf course, or forest stand (Conover 1992; Sullivan et al. 1996; Whisson 1996).

Despite these limitations, studies have shown that both approaches to habitat manipulation, either reducing pest density or diverting the pest away from the commodity, are promising for reducing damage in certain situations. Further research is needed.

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WILDLIFE DAMAGE AND CONTROL RESEARCH AND EXTENSION PROGRAMS: COST RECOVERY STRATEGIES

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ABSTRACT: This paper discusses cost recovery strategies for vertebrate pest control research and extension programs. It gives an historical background using California examples about how these programs have been supported in the past. Current situations and future trends in supporting research and extension in the vertebrate pest area are also discussed.

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INTRODUCTION

The Land Grant University system is key to agricultural research and extension programs in the United States. In the 1880s, the U.S. began the Land Grant system. Each state was given a grant of land, its size based on the population of that state. The state was then able to sell that land or, in other ways, use it to support establishing the Land Grant University for that state. The Land Grant System was conceived to bring the University to the people. Prior to that time, most universities were focused on philosophical teachings and were exclusive for relatively few people in the country or world.

The Land Grant system changed this approach significantly. It has served as a model for change in the university system throughout the world. The basic components of the Land Grant system are teaching, research, and extension. It created a new relationship between the universities and the people. An important aspect was access to the universities and their information. The Land Grants were available to "the common people" throughout the country. Second, the university programs were designed to deal with practical information to solve people's problems. The third part was the emphasis on application of research to specifically deal with individual and community needs. The result was a university system very different from the past. Instead of looking inward and being primarily theoretical or philosophical in their teaching and research, they became problem-solvers and educators for the people of the United States. In California, the Land Grant University is the University of California.

Not only did the Land Grant system provide resources for starting these new universities, it provided the framework and base funding to support research and extension efforts in agriculture, including Cooperative Extension. This continuous base support for Cooperative Extension and the Agricultural Experiment Station, as well as other public support for vertebrate pest control, had tremendous impact on our vertebrate pest research and extension efforts. It definitely affected the view or expectation of how programs should be developed and supported. Now, support levels are changing, and the author believes we need to examine past support and develop strategies for support in the future.

Many remember how vertebrate pest control research, extension and, indeed operations, were funded in the past. Without understanding how this funding has changed, we are subject to being caught off-guard with current and future funding trends. While these remarks use California examples, the author believes similar trends have and will continue to happen throughout the world.

PUBLIC SUPPORT FOR RESEARCH AND EXTENSION

It is instructive to review public support for Cooperative Extension and the Agricultural Experiment Station, two of the major components of the Land Grant system. In California, base funding steadily increased from shortly after World War II to 1967 (Scheuring 1995). These increases were regular and predictable. While there were never "enough" resources to address the varied vertebrate pest problems in the state, funds (and people) were directed toward the important vertebrate pest problems.

In 1968, this regular upward trend started to change. For the first time, the budget was cut. This "one time" 3% cut signaled the end to regular and predictable budget increases for research and extension. During the 1970s and 1980s, the true impact of inflation was generally unrecognized. This, coupled with no base budget increase, started to erode funds significantly.

During this time, there was also a general increase in government ear-marked funds. These were targeted to specific programs such as Integrated Pest Management or Small Farms. And, during the 1990s, the University of California budget in this area decreased by more than 20%. Unfortunately, these cuts have been permanent.

The point of this is to highlight that public funds for research and extension began to decline in the 1970s and has continued to do so to this day. These trends, unfortunately, are repeated in many, perhaps most, publicly funded vertebrate pest research and extension programs in the world.

OTHER SUPPORT IN CALIFORNIA

Other changes have occurred that have significantly impacted vertebrate pest control research, extension, and operations. In the past, the California Agricultural Commissioners were very involved in applied research and extension efforts. They had vertebrate pest specialists on staff; they developed, manufactured, and applied bait for vertebrate pest control; and they trained farmers in using vertebrate pest control materials. The California Department of Food and Agriculture (CDFA) District Biologists dealt with vertebrate pest control and did considerable applied research and demonstration in this important area. They were also involved in rodenticide and avicide registrations. The universities, both the University of California and the California State University system, had significant research and extension programs in the areas of vertebrate pest control. Also, United States Department of Agriculture (USDA) Animal Damage Control (formerly U.S. Fish and Wildlife Service) had cooperative programs in the majority of California's counties. They, too, conducted considerable research on vertebrate pest problems. Each of these entities continues to play significant roles in vertebrate pest control but, while the commitment remains, the overall effort, it is felt, has diminished. A major factor in this trend has been relatively constant funding declines and increases in responsibilities. Without future increases in funding or new funding sources, the overall trend, it is feared, will continue on its downward path.

STRATEGIES FOR SUPPORT

Three possible strategies for support of vertebrate pest control research and extension are: cost recovery, user assessments, and collaboration. Obviously, there are many more that could be covered.

Cost Recovery

A national email survey was conducted of Cooperative Extension Directors in each state plus several U.S. territories in August 1997. Response to the survey was very good with 72% of those surveyed responding. In this survey, questions dealt with cost recovery in extension programs.

First, all Extension Directors who responded (n=39) were recovering costs for some extension programs. About 89% were charging for services such as diagnostic tests. Seventy-three percent (73%) of the states charge for at least some publications. About 57% were charging for some classes and workshops, and 30% were charging for typical extension meetings. Twenty-eight percent (28%) were charging subscriptions for newsletters but only 3% were charging for individual consulting.

Extension has a tradition of being "free" and this affects the attitude about charging for programs or materials. Since Extension is tax supported, many believe free access to programs must be provided. In fact, this is the general policy of the U.S. Department of Agriculture, the Federal agency providing base funds for Extension programs. About 76% of the states provide free or reduced fees for their programs to people with economic needs; 81% waived the fees on request; 79% waived fees with documentation, and 69% used general waivers for some programs.

The survey asked about the reactions when charging for Cooperative Education (CE) programs. This is important because it gives ideas to those who may start charging for their Extension, research or operational efforts. The staff (CE county and state staff) were 40% negative about charging for the programs. A similar amount (38%) thought it was a positive experience. Most administrators (72%) had no problems with charging. For customers that were using the information for business purposes, like improved farm management, 58% were positive. When people were using the information or programs for personal issues, like controlling gophers in their yard, about 42% were positive about paying as opposed to getting the information for free.

User Assessments

Another way of supporting research and extension programs in California has been user assessments such as the Rodent Bait Surcharge Program. In 1990, California passed a law to create the Bait Surcharge Program. This program is a good example of the ability to support programs in a different way than simply getting money from the general public. CDFA holds rodenticide registration labels, and these baits are sold and distributed by County Agricultural Commissioners. For all baits sold, there is a $.50/lb surcharge collected. One hundred percent (100%) of the funds from this surcharge are used to conduct research on vertebrate pests. How has it worked? Approximately $500,000 is collected each year from the surcharge. With that money, CDFA has been able to meet Environmental Protection Agency (EPA) registration requirements for all CDFA rodenticide labels. The Department has formed partnerships with organizations and groups like the USDA National Wildlife Research Center and some private entities. This allowed a pooling effort to maintain or obtain rodenticide registrations. Vertebrate pest control research has been conducted which looks at improving existing, and finding alternative, control strategies. There have also been projects funded on bird trapping, different bait station designs, and economic analysis of damage, just to name a few.

Collaboration

Building collaborative relationships has been extremely important in better addressing vertebrate pest control problems. This is especially true with operational programs that are now using recharge when collaborating with other agencies. Also, research efforts, in many cases, are branching out to build partnerships and other kinds of relationships between universities and also with private industry. The Bait Surcharge Program is an excellent example. Funding for research projects to universities and agencies, several outside California, brings a much greater (and diverse) effort to bear on understanding and solving vertebrate pest problems. These collaborations have been greatly enhanced in recent years because of alternative funding and support programs.

DISCUSSION

So what does all this mean? First, public-based budget support is declining for Vertebrate Pest Control Research and Extension, and nothing is seen in the future that would suggest this will change. Second, funds received are increasingly targeted to specific projects, reducing the ability to research many important issues without extra funding.

To deal with these funding shortfalls, there is a need to continue to change and look at new methods of support. User fees and assessments, and charging for research, extension, and operations efforts will become increasingly important. There will be an increase in grants and contracts which will focus programs on areas where money is available. While these are generally programs with high-priority, they are not necessarily the highest priority for the general public. Increased collaboration efforts to address important issues will also be seen. For example, the USDA continues collaborating with United States Fish and Wildlife Service (USFWS) on vertebrate pest control programs protecting endangered species where Fish and Wildlife pays for the efforts to conduct those programs.

In conclusion, the author wants to leave you with a visual image, a perplexed vertebrate pest control worker saying "we are doing such good work, why don't they keep sending the money?" That's something that we all need to think about. Just because we are doing good work and addressing important issues, it doesn't mean that the money (or public support, in general) will keep coming. It is up to each of us to find support for important vertebrate pest research and extension programs.

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ARE BARN OWLS A BIOLOGICAL CONTROL FOR GOPHERS? EVALUATING EFFECTIVENESS IN VINEYARDS AND ORCHARDS

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ABSTRACT: Several rodent species cause damage in vineyards and orchards. Current efforts to reduce chemicals used to control rodents are encouraging development of alternative practices, such as biological control. For several years growers in California have been installing artificial owl nest boxes to attract barn owls with the hope of reducing rodents, especially gophers, through predation. Effectiveness of barn owls as biological control of gophers in vineyards and orchards is unknown. The purpose of the study was to use growers surveys and diet analysis to assess the effectiveness of installing barn owl nest boxes to control gophers. Surveys of growers that installed artificial nest boxes reported that 40% of boxes were occupied within six months of installation. Of those growers with occupied nest boxes, however, only 23% felt that barn owls were effective in controlling gophers on their lands. The diet results indicated that barn owls most frequently prey upon gophers and voles. Barn owls prey upon both adult and juvenile gophers, and juvenile gophers were especially vulnerable during spring and summer. The findings provide little evidence that barn owls are effective in controlling gophers. With further research the approach might prove useful, but only when used in concert with other control approaches such as trapping and rodenticides.

KEY WORDS: barn owls, *Tyto alba*, survey, pocket gophers, *Thomomys bottae*, rodent control, diets

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INTRODUCTION

Bottas pocket gopher (*Thomomys bottae*) is a serious rodent pest in many California orchards and vineyards. Active throughout the year, they can increase to high numbers if not controlled, causing damage and loss of vines and trees and interfering with irrigation and other cultural operations (Salmon et al. 1992). Pocket gophers are often managed by trapping and use of toxic bait, usually strychnine, delivered manually by a probe or by a mechanical bait applicator (Marsh 1992). While strychnine baiting continues to be a primary control method on many farms, an increasing number of farmers are seeking alternatives to the use of rodenticides because of safety concerns for domestic animals, raptors, and other animals.

As a result of the desire to continue gopher control and reduce rodenticide use, hundreds of farmers in California and nationwide have installed artificial nest boxes to attract barn owls (*Tyto alba*) to farms as part of a rodent management strategy. The prey species most often taken by barn owls are meadow voles (*Microtus californicus*), pocket gophers, and mice (*Cricetid* sp.) (Ingels 1995). Barn owls readily adapt to artificial nest boxes (Marti et al. 1979). Availability of nest sites appears to be the factor limiting barn owl population growth in habitats disturbed by humans, including agricultural areas (Taylor 1994). Barn owls rarely display any territorial behavior, except in the vicinity of the nest site (Smith et al. 1974; Taylor 1994) which enables farmers to attract many breeding pairs to relatively small areas.

Despite the widespread interest in attracting barn owls to farms, the efficacy of artificial nest boxes in promoting owl numbers and controlling rodents in vineyards and orchards is unknown. The purpose of this study was to use grower surveys and diet analysis to assess the potential of installing barn owl nest boxes in gopher management. The results of the survey will provide information on nest box occupancy characteristics and on the perceived effectiveness of this rodent control. Pellets regurgitated by barn owls contain intact skeletal remains of rodent prey consumed and can be used to ascertain composition of diet.

METHODS

Surveys

In 1995, questionnaires were mailed to 207 farmers which had previously received information packets on barn owls from the Sustainable Agricultural Research and Education Program, at University of California, Davis, from 1993 to 1995. Farmers were asked about: 1) reasons the growers wanted to install barn owl nest boxes; 2) the severity of pest problems, particularly in regards to voles and gophers; 3) the proportion of nest boxes occupied within the first year; and 4) the perceived effectiveness of barn owl presence in controlling vertebrate pests.

Diet Analysis

Ten growers in the Lodi Grape Growing District of the northern San Joaquin Valley were randomly selected to participate in the field research studying the composition of barn owl diets. Crop types within 100 meters of nest boxes consisted of: 1) vineyards; 2) orchards; 3) vineyards and orchards; 4) vineyards and fallow land; 5) vineyards and alfalfa; and 6) orchards, vineyards and alfalfa. The authors selected 38 nest boxes installed by ten growers and collected pellets deposited by barn owls from within and beneath each nest box at regular intervals throughout the nesting season in 1996.

Individual pellets were gently broken up by hand and all skeletal parts were analyzed for prey identity. Skeletal remains were identified by comparison with mammal and bird specimens in the Museum of Wildlife and Fisheries Biology, University of California, Davis. Percent frequency of occurrence of prey items among pellets for each collection interval were calculated. To determine the average number of gophers eaten by one pair of owls during the nesting season, the number of right mandibles of gophers found in pellets were counted. The mandible length was measured to estimate occurrence of juvenile gophers in barn owl diets.

RESULTS

A total of 88 people responded to the survey for a 43% response rate. Of the respondents, 55 had installed a total of 241 artificial nest boxes. Only survey results from 55 respondents that had installed nest boxes are reported. Forty-eight percent of farmers reported that the most important reason they installed owl nest boxes was to control vertebrate pests. Thirty-six percent of the individuals installed boxes for a hobby, 2% of respondents hoped to increase wildlife on their farm, and the remaining 12% installed boxes for other reasons.

Pocket gophers were considered a moderate to severe pest problem by 77% of respondents prior to nest box installation; 18% of people replied that gophers were only a slight or non-existent problem and the remaining individuals were unsure. Only 9% of farmers answered that meadow voles were a moderate or severe pest. Thirty percent of people felt meadow voles were a slight or non-existent pest problem and the remaining 61% were not sure or had no answer.

Respondents reported that 40% of the nest boxes were occupied by barn owls in 1995. Seven percent of individuals felt that installation of nest boxes to attract barn owls was very effective in controlling gophers. Another 16% of respondents considered nest box installation somewhat effective, and 11% thought they had no effect at all. The remaining 66% were not sure or had no answer. Installation of owl boxes to control meadow voles was considered very effective by 2% of respondents and somewhat effective by 7%. Twelve percent of individuals thought the approach was not effective and the remaining 79% were not sure, or had no answer.

Preliminary diet analysis indicated that gophers and voles were the two most abundant prey in barn owl pellets, each occurring in over one-third of pellets. Occurrence of gophers increased in spring and summer, probably because barn owls were preying upon abundant juvenile gophers. On average, a pair of nesting barn owls consumed a minimum of almost one gopher per day during the nesting season. Predation on gophers did not appear to vary according to crop type; when comparing boxes located in vineyards with those located in orchards, both frequency of gophers on diets and minimum number of gophers eaten were similar.

DISCUSSION

Results of the survey indicate that controlling vertebrate pests was the most common reason why respondents had installed nest boxes. Most respondents had previously received literature on barn owl nest boxes as alternatives to vertebrate pest management; this literature included estimates of nesting pairs of owls and young consuming over a thousand rodents per nesting season (Colvin 1986). Installation of nest boxes for barn owls has been shown to double the number of breeding pairs in a given area and also produce significantly larger clutches (Johnson 1994). The recent increase in installation of barn owl nest boxes may reflect a concern with the risks posed to non-target wildlife and domesticated animals.

The survey showed that installation of nest boxes is successful in attracting barn owls. Farmers replied that about 40% of boxes had been occupied. Many respondents indicated that they had installed the boxes during or after the nesting season, after which owls were unlikely to occupy nests. The reported occupancy may be underestimated. Although literature had been previously distributed to farmers to help in assessing owl occupancy, determination of occupancy often requires physical inspection inside the box.

Most individuals considered pocket gophers a moderate to severe pest problem prior to nest box installation, but only a few considered meadow voles a moderate to severe pest. Although almost one-quarter of farmers felt that the installation of nest boxes that attracted barn owls had an effect on their gopher problems, over two-thirds were not sure of any effect or had no answer. A few people felt that nest box installation had an impact on their vole problems, while most were not sure. Even though sample sizes were small in the survey, the results suggest that there is little substantive evidence for growers to ascertain positive effects of nest box installation reducing gopher or vole problems.

Previous diet studies in California indicate that pocket gophers are an important prey item of barn owls (Smith and Hopkins 1937; Hawbecker 1945; Fitch 1947; Clark and Wise 1974). Although previous studies show that various predators will take vertebrate pests, only one study to date has shown a dramatic decline in the pest species after the initiation of a large-scale owl nest box program. A pest management strategy in the oil palm estates of peninsular Malaysia used barn owls as a biological control to reduce toxic baiting in control of rats (Duckett and Karuppiah 1990). The objective was to increase barn owl population density with the installation of 200 nest boxes on 1,000 hectares of oil palms. Within 19 months predation by barn owls, without any baiting program, had reduced rat damage to palms from a record high of 19.5% in June of 1988 to 1.4% by January of 1990 (Duckett and Karuppiah 1990). Other evidence that predators may control pest populations comes from studies conducted in pine plantations in Chile where habitat modifications appears to have increased predation of rodent and rabbit species by barn owls and foxes (Munoz and Murua 1990). Observations during a radio-telemetry study on barn owls hunting in agricultural areas in Israel showed a reduction in voles and house mice (Kahila 1991).

The diet analysis indicates that gophers and voles are the major prey of barn owls and suggests that juvenile gophers are especially vulnerable during spring and summer. Gophers are substantially larger than voles, indicating that gophers are the dominant prey of barn owls. Crop type does not appear to influence vulnerability of gophers to owl predation. However, the fact that barn owls prey principally upon gophers and eat substantial numbers does not mean that barn owls can control gopher numbers.

In conclusion, the results indicate that installation of artificial nest boxes will attract barn owls. However, whether or not this will result in effective gopher control is unknown. Some growers felt that attracting barn owls was effective in controlling gophers, but the number was relatively small. Further, the fact that barn owls eat numerous gophers does not mean that this predation is sufficient to effectively reduce gopher populations and reduce damage. Perhaps the installation of nest boxes would prove useful in an integrated approach that also incorporates the use of trapping or rodenticides.

Many people install barn owl boxes as a hobby or to improve wildlife on their farms, and the authors support these efforts. However, for those who install boxes in hopes of controlling gophers, the authors believe it is essential that they realize there is little, if any, evidence that their efforts will be effective.

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RABBIT CALICIVIRUS: UPDATE ON A NEW BIOLOGICAL CONTROL FOR PEST RABBITS IN AUSTRALIA

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ABSTRACT: Rabbit calicivirus disease (RCD), also known as rabbit haemorrhagic disease, is being used to control wild rabbits in Australia. Deliberate release of RCD followed extensive non-target animal and human testing and consideration of some 472 submissions. A national monitoring and surveillance program is in place to quantify the impact of RCD on rabbits, rabbit damage, predators, competitors, and ecosystems. Preliminary data suggest wide spatial variation in RCD impact, from no observable effect to >90% mortality and marked response in competitors and vegetation. This paper provides an overview of rabbit impact in Australia, details of the considerations and testing that preceded a decision to release, and results of impact studies to date.

KEY WORDS: European rabbits, rabbit haemorrhagic disease virus, biological control

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INTRODUCTION

Biological control is the use of "parasites, predators and pathogens to regulate populations of pests" (Harris 1991). It has terrific appeal as an inexpensive and convenient form of control with low, if any, maintenance costs. However, many of the species introduced to control a pest have exerted little or no control or have become pests themselves. An international survey of biological control of weeds found 76% of agents failed completely, 6% were spectacularly successful, and 18% had limited success (Briese 1993). Biological control of vertebrate pests is less common than that of weeds, but also has a checkered past. In Australia, biological control has had complete failures; for example, releasing cats to control rabbits, possibly adding to the feral cat problem and releasing chicken cholera, which does not infect rabbits, for rabbit control (Rolls 1969), and one spectacular success, myxomatosis for rabbit control (Fenner and Ratcliffe 1965). Australia and New Zealand have also recently released a new agent, rabbit haemorrhagic disease, known as rabbit calicivirus disease (RCD) in Australia and New Zealand, to control rabbits. Rabbit calicivirus has been active in Australia since late 1995 and New Zealand since mid-1997, with variable effects on rabbit populations. In Australia, RCD continues to affect rabbit populations two years after its initial release and there are encouraging early signs of responses in vegetation and introduced predators, but it is too early to conclude how effective it will be in controlling rabbit damage. In this paper, the authors explore some general principles of biological control and pest management before describing the assessment, escape, release, and impact of RCD in Australia.

WHY USE BIOLOGICAL CONTROL?

Biological control appeals as a inexpensive and efficient means of controlling pests and the damage they cause. Biological control agents have the potential to be species-specific, making them safe for non-target species. They are also inexpensive to use because they are self replicating and naturalizing. These potential advantages are not without disadvantages; agents that are self-replicating are also unmanageable, their ability to naturalize also makes release irreversible, and testing species-specificity and safety contributes to significant start up costs. As well, any error may impose irreversible risks on people and other species. It is interesting to note that many of the cons are the reverse of the pros (Table 1).

Table 1. Pros and cons of biological control agents.

Pros	Cons
inexpensive	start up assessment costs
species specific	? human and other health risks
self-replicating	unmanageable
naturalizing	effectiveness declines
	uncertainty

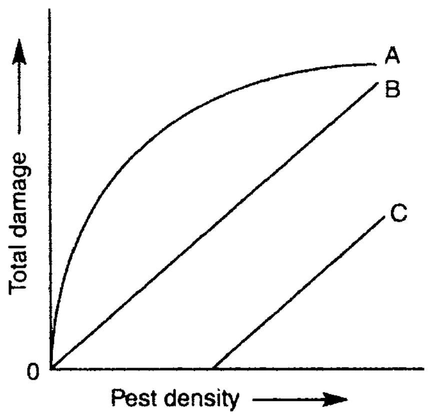
WHAT NEEDS TO BE CONSIDERED IN ASSESSING BIOLOGICAL CONTROL?

Deciding whether or not to implement biological control for a pest or weed species requires a scientific assessment of the safety and effectiveness of the proposed agent. It also requires a scientific assessment of the ecology of the pest species, the likely interaction of the agent and pest species, and options for integrating biological control with other management techniques (Briese 1993). This initial scientific assessment costs, often significantly, and the economics of a biological control program also need to be considered during the assessment.

Norton (1988) and O'Brien (1991) proposed that to be successfully adopted, new pest control methods and other land management practices need to be: technically possible, effective, practical, economically desirable, environmentally acceptable, politically acceptable, and socially acceptable. Successful biological control programs depend on more than scientific and technical input; they also require the support of land managers and the public.

HOW MUCH CONTROL IS ENOUGH?

The damage caused by the pest needs to be identified and some understanding reached of the nature of the relationship between pest density and damage, which is often not linear. The relationship may vary because of the nature of the pest action, the resource to be protected, and seasonal conditions (Braysher 1993). A linear relationship between pest density and damage, in which removing pests produced a corresponding direct reduction in damage is often assumed, but may be too simplistic (Figure 1b). For some pests, damage may remain low until a threshold density of pests is reached (Figure 1c). Under other conditions, pests may cause considerable damage, even at low densities (Figure 1a). For some pests, different relationships between density and damage will operate under different circumstances. This is likely to be true for rabbits as pests of pasture, rare native plants, and prey of feral cats and foxes.



Adapted from Bomford, M. in Parkes et al. 1996.

Figure 1. Theoretical relationships between pest density and damage. Figure 1a represents the situation where pests may cause considerable damage, even at low densities. Figure 1b represents a linear relationship between pest density and damage, in which removing pests produces a corresponding direct reduction in damage. Figure 1c represents where damage remains low until a threshold density of pests is reached. For some pests, different relationships between density and damage will operate under different circumstances.

Biological control agents, by their very nature, tend to be more active when the host is at high densities. Therefore, they are most likely to be effective when there is a minimum threshold density before damage is caused, less likely to be effective when the relationship is linear and least likely to be effective when the pest causes damage at very low densities.

Realistic objectives for the control program, based on an understanding of the damage/density relationship will also assist assessment. For example, with some pests the appealing idea of reducing the pest population may not result in any damage reduction.

WILL THE BIOLOGICAL CONTROL AGENT CONTINUE TO BE EFFECTIVE?

Biological control agents are likely to become permanent components of the environment. The advantage of this is that they can affect the pest over a considerable period from a single release and provide relatively inexpensive pest control. The disadvantages are that a decision to release a biological control agent is irreversible—the genie cannot be put back in the bottle! Myxoma virus, initially found in cottontail rabbits in the Americas and found to be lethal to European rabbits, was introduced into Australia in 1951 after more than 30 years research and now occurs in wild rabbits over vast areas of Australia. Myxomatosis, the disease caused by myxoma virus, involves unsightly and painful infections in the eyes and genitals and usually takes two weeks to kill. Given current thinking about animal welfare, myxomatosis is not an acceptable form of rabbit control to many, but there is no way of stopping its effects on wild rabbits.

Biological control agents may decline markedly in effectiveness over time. As part of the environment, biological control agents and their hosts are subject to the same evolutionary rabbits with genetic resistance to myxomatosis were detected and changes to the virulence of the myxoma virus were detected within two years (Fenner and Ratcliffe 1965). Over the next 45 years, the virus and rabbits have continued to evolve together, with the virulence of the virus continuing to change and Australian wild rabbits being selected for resistance to myxomatosis. This co-evolution not only means that the effectiveness of the control agent may decrease over time, but also compromises any later releases of the agent which would have to compete with less virulent field strains to control the host.

ARE BIOLOGICAL CONTROL AGENTS COST-EFFECTIVE?

The development of biological control programs involves high initial costs for testing, which need to be weighed against the potential long term benefits. The duration and magnitude of the benefits are unknown, and probably unknowable, in advance. Nevertheless, estimates can often be made. Reasonably accurate estimates of the cost of establishing a biological control program can usually be made. If the biological control program needs to be integrated with other control measures, the costs of the integrated control program also need to be considered. Less accurate are estimates of the potential value of the program in reducing pest damage, often based on poor estimates of the damage caused by the pest and the great difficulty involved in estimating how much damage will be prevented, and for how long. For many pests, other economic factors also need to be considered such as the potential resource value of the pest. Feral goats, pigs and wild rabbits in Australia are sold domestically and exported as game meat. These industries are relatively small when compared to the damage caused by the pests but they have potential to expand and any biological control program will compromise these industries. All these factors need to be taken into account when considering the economic desirability of biological control programs and unless the costs and benefits are vastly different, the assessment can be problematic.

WHAT DOES THE AUSTRALIAN PUBLIC THINK ABOUT BIOLOGICAL CONTROL?

In Australia, the public were invited to provide submissions indicating support or opposition to the release of rabbit calicivirus, and to comment on any possible adverse effects on people, groups, or the environment from controlling rabbits or releasing the virus. Of the 472 responses, there was overwhelming support for releasing RCD, 78% supporting release and 9% opposing. A similar exercise in New Zealand found the public was much more evenly divided. The support in Australia reflects widespread community recognition that rabbits are significant agricultural and environmental pests (Williams et al. 1995).

The main concerns raised by the public were: the species specificity of RCD (i.e., that it could infect species other than rabbits); that the predators of rabbits would turn on native animals and livestock; and effects on the rabbit industries and animal welfare concerns.

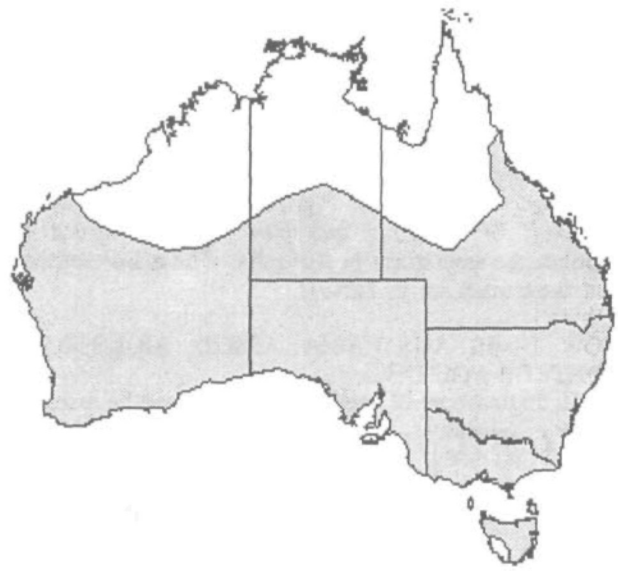
WHY ARE RABBITS A PEST IN AUSTRALIA?

Rabbits are considered a pest to both agriculture and the environment in Australia. They are an introduced species which established in the wild in 1859 when wild rabbits were introduced to be hunted and rapidly bred and spread. Rabbits have since spread through almost every environment south of the Tropic of Capricorn, except in dense forests, on black soil plains, and above 1,500 meters (see Figure 2) (Williams et al. 1995).

Rabbits harm agriculture by competing with stock for pasture, especially during drought; damaging crops, forestry and tree plantations; contributing to land and vegetation degradation; and costing farmers for pest control. On the environmental side, rabbits damage native flora; compete with native fauna; the predators of rabbits attack native fauna; and rabbits contribute to soil erosion, land degradation, and reduction of water quality.

Sloane et al. (1988) estimated the loss to wool production in Australia due to rabbits as $90 million per year. The total cost to the nation is less certain, with estimates as high as $600 million per year (Wilson 1996), although this estimate is considered too high (Foster and Telford 1996).

As a result of these impacts and costs, extensive rabbit control is undertaken using poisoning with 1080 (sodium monofluoroacetate), warren destruction ("ripping"), and exclusion fencing. Myxomatosis is also widespread and exerts significant population control in some areas. Despite these actions, rabbits remain widespread pests and are declared "noxious" throughout Australia (Williams et al. 1995).



Source Williams et al 1995

Figure 2. Distribution of rabbits in Australia.

WHAT IS RABBIT CALICIVIRUS?

Viral haemorrhagic disease of rabbits (VHD) was first detected in China in 1984 in rabbits imported from Germany (Liu et al. 1984). It spread rapidly across Asia and Europe killing millions of rabbits, particularly farmed rabbits, until the late 1980s when effective vaccines were developed. It also spread to wild rabbit populations in Europe. In Europe and Asia, VHD was considered a production problem for rabbit farming and a conservation problem for wild rabbits and their predators. It was thought to be spread by humans, food, bedding and rabbit-to-rabbit contact (Morisse et al. 1991). Insects were also known to be capable of spreading VHD (Gehrmann and Kretzschman 1991).

The causative agent of viral haemorrhagic disease has now been shown to be a member of the calicivirus family, known in Australia and New Zealand as rabbit calicivirus. A similar syndrome, also caused by a calicivirus, is found in hares; European brown hare syndrome (Morisse et al. 1991). Adult rabbits infected with rabbit calicivirus in the laboratory become progressively quieter from 18 to 24 hours after infection, develop a temperature, and become comatose and die quietly 6 to 12 hours later. The death rate, especially in adult farmed rabbits, can be as high as 90% (Morisse et al. 1991), although rabbits younger than eight weeks tend to have higher survival rates.

WHY LOOK AT RCD FOR AUSTRALIA'S RABBITS?

A potential new biological control agent for wild rabbits held considerable appeal in Australia. It had the potential to supplement the waning effectiveness of myxomatosis, would be species-specific and less costly than conventional techniques such as ripping rabbit warrens, poisoning, fumigation, and fencing.

In 1989, the Conservation Ministers of Australia agreed to start investigations into RCD, which was spreading rapidly across Europe and Asia, to assess its potential as a biological control agent for rabbits. Following this promising initial assessment in both the laboratory and field, the Agriculture and Conservation Ministers of Australia and New Zealand agreed to continue the assessment in Australia. The main events in that assessment are in Table 2.

HOW DOES AUSTRALIA ASSESS BIOLOGICAL CONTROL AGENTS?

Biological control agents in Australia can be assessed using a legislative process, defined in the Biological Control Act 1984. The process requires the unanimous agreement of the Commonwealth, State and Territory, and New Zealand Agriculture and Resource Management Ministers, known as the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), to commence the process of nominating biological control agents and targets by seeking public comment. The Minister is required to consider the public submissions, a task which he has delegated to the Bureau of Resource Sciences.

The Biological Control Act requires that the Minister be satisfied that the nominated pest (target) causes harm, that it is controllable by biological means, and that any harm caused by controlling the pest is less than the benefit from failing to control the pest. Similarly, for the proposed agent, it needs to be able to control the pest and any harm caused from releasing the agent, other than that from controlling the pest, needs to be less than the harm from not controlling the pest, or using other means to control the pest. The main issues raised in the submissions are considered below.

The Bureau of Resource Sciences recommended to the Minister that the requirements for agent and target organisms were met, and the Minister consulted his ARMCANZ colleagues to make the relevant declarations. ARMCANZ members unanimously agreed to declare rabbits a target organism and RCD agent organisms in September 1996. Similar declarations were later made in all States and the Northern Territory to authorize release in those jurisdictions.

IS RCD SAFE?

In 1991 the virus was imported into the microbiologically secure Australian Animal Health Laboratories to test its species specificity and effectiveness. Thirty-three non-target species were inoculated with a dose of rabbit calicivirus and subsequently tested by a range of tests for signs of infection (Table 3). The tests used for detecting RCD were clinical signs of disease, sentinel rabbits, antibody detection by indirect and competition enzyme linked immunosorbent assays, polymerase chain reaction and histological examination of tissues. Suspicious tissues found by histological examination could be subjected to specific immunofluorescence and immunoperoxidase staining, however, no tissues from non-target species have required this testing. These tests did not detect any infection of any non-target species by rabbit calicivirus. RCD was found to be 98% effective in killing adult Australian and New Zealand laboratory and captured wild rabbits (Lenghaus et al. 1994).

A literature review of the testing of non-target species by laboratories overseas found 14 studies in which 26 non-target species were tested with no reports of disease caused by rabbit haemorrhagic disease in any non-target species (Bureau of Resource Sciences 1996).

WILL RABBIT CALICIVIRUS HARM PEOPLE?

Despite the wide international occurrence of RCD and corresponding human exposure, there is no evidence of illness or disease in humans. Since there was considerable concern raised about the possibility of humans being infected with rabbit calicivirus and there were no specific studies of human health in the literature, the Australian Government commissioned a study to compare people exposed to RCD with a similar group not exposed. The study consisted of serological assessment and a health questionnaire of participants, and a survey of international laboratories working with the virus.

The study found all blood samples were negative to antibodies to rabbit calicivirus and no difference was found between those exposed to the virus and those not exposed. There was also no difference found in illnesses reported from the two groups. The overseas laboratories which replied to the survey did not report any illness associated with exposure to rabbit calicivirus, and where any testing for antibodies has been done, all reported negative results (Anon 1996).

WHAT ABOUT THE RABBIT INDUSTRIES?

Rabbit industries in Australia have concentrated on harvesting wild rabbits, mainly in the arid inland areas. The best cuts of meat are used for human consumption, the off-cuts for pet food and the fur from the pelts for hats, including the famous Akubra, with a small number of pelts used for clothing. The size of the industry varies, depending on the season and disease. The export market for Australian rabbit meat increased in the late 1980s, thought to be due to the effects of RCD in China and Europe, and decreased markedly from 1992, due to drought. The total value of Australia's wild rabbit industries is estimated at \$9.1 million for rabbit meat and byproducts, and \$10.7 million wholesale for hat production. The industry is thought to employ the equivalent of 68 full time shooters and 70 meat processes (Foster and Telford 1996). The rabbit meat industry virtually ceased following the escape of RCD in 1995.

Table 2. Main events in assessing RCD in Australia and New Zealand.

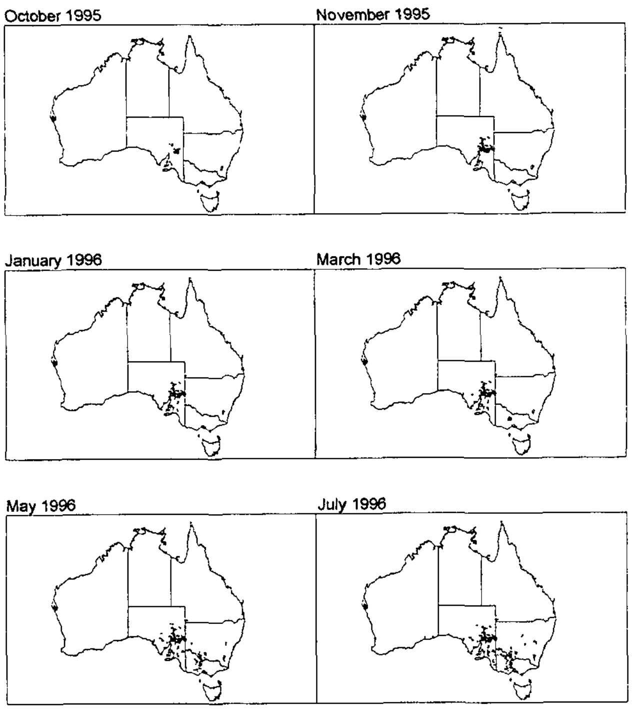
Date	Event
1984	RCD discovered in China
1984-1988	RCD spreads rapidly in Europe and Asia.
1989	Australian conservation ministers agree to investigate RCD for rabbit control by studying the effects and biology in Europe
1991	RCD imported for laboratory tests in Australia
March 1995	Island field trials commence in Australia
September 1995	RCD escapes from trial site and spreads across South Australia
September 1996	ARMCANZ Ministers authorize release of RCD
October 1996	Official releases of RCD commence
July 1997	New Zealand government decides not to introduce RCD
August 1997	RCD discovered in New Zealand

Table 3. Australian and New Zealand testing of non-target species for infection with rabbit haemorrhagic disease virus (Bureau of Resource Sciences 1996).

Australian and New Zealand Species Tested	Imported Species Tested
Bush rat (*Rattus fuscipes*)	Horse
Spinifex hopping-mouse (*Notomys alexis*)	Cow
Plains rat (*Pseudomys australis*)	Deer
Fat-tailed dunnart (*Sminthopsis crassicaudata*)	Sheep
Northern brown bandicoot (*Isoodon macrourus*)	Goat
Brush tailed bettong (*Bettongia pencillata*)	Pig
Tammar wallaby (*Macropus eugenii*)	Dog
Brushtail possum (*Trichosurus vulpecula*)	Cat
Long billed corella (*Cacatua tenuirostris*)	Fox
Silver gull (*Larus novaehollandiae*)	European brown hare (*Lepus capensis*)
Brown falcon (*Falco berigora*)	Ferret
Emu (*Dromaius novaehollandiae*)	Rat
Eastern blue-tongue lizard (*Tiliquia scincoides*)	Mouse
New Zealand lesser short tailed bat (*Mystacina tuberculata*)	Fowl
North Island brown kiwi (*Apteryx australis*)	Feral pigeon
Short-beaked echidna (*Tachyglossus aculeatus mantelli*)	
Southern hairy-nosed wombat (*Lasiorhinus latirons*)	
Koala (*Phascolarctos cinerous*)	

THE ESCAPE

Field testing of RCD in wild rabbits began on Wardang Island in March 1995. These trials were designed to examine the effect of RCD on rabbits in the Australian environment. They showed that RCD can be transmitted between Australian wild rabbits living in warrens and between warrens. In October 1995, RCD escaped from the island to mainland Australia and then rapidly spread over a large area of South Australia and *into* parts western New South Wales and southwest Queensland by December 1995 (Figure 3). Virus activity declined over the summer months but, in March 1996, RCD became active in central Victoria and spread in that state. The reasons for the escape have not been conclusively established, but insect vectors are considered most likely to be responsible.



Source Bureau of Resources Sciences 1996 report

Figure 3. Maps of the spread of RCD from November 1995.

RELEASES

In October 1996, RCD release was authorized by all Australian governments with all mainland states making releases that year. Tasmania did not release RCD, but it was reported in the northern part in December 1996 and spread slowly. Releases in other areas of Tasmania have also been made without the rapid and spectacular effect seen in the arid areas where RCD escaped.

WHERE IS RCD NOW?

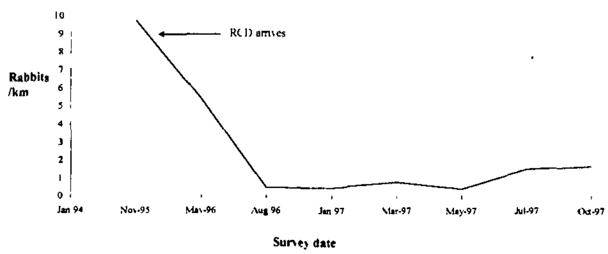
From the initial escape and the more than 700 subsequent releases of RCD, the virus is now thought to be distributed roughly over the entire distribution of rabbits in Australia, with the possible exception of north-western Australia (Figure 2).

HOW DOES RCD SPREAD?

RCD is spread by rabbit fleas and mosquitoes (Lenghaus et al. 1994). Following the rapid spread across Australia, other vectors have also been sought. Bushflies have been shown to spread RCD in the laboratory, and many other bush and blow fly species have tested positive to the presence of viral RNA. The role of these insects in virus transmission in not yet known.

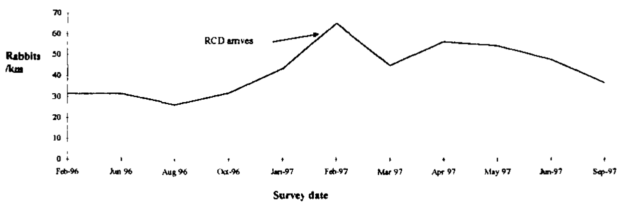
WHAT EFFECT IS RCD HAVING?

At the national scale, the impact of RCD on rabbit populations has been variable, from the initial spectacular epizootic in some regions, with mortality rates around 90%, to the patchy, less obvious impact in other areas following releases. For example, Erldunda in the Northern Territory measured declines during the initial epizootic of about 90% (Figure 4), while rabbits numbers in parts of the Western Slopes of New South Wales continued to increase after RCD arrived (Figure 5). RCD has been found to be more effective in arid and semiarid areas (rainfall less than 300 mm per year) than in the wetter areas. RCD recurs with three roughly annual epidemics recorded at a site in the Flinders Ranges, South Australia, and two recorded at Lake Burrendong, New South Wales. The mortality rate recorded at the Flinders Ranges site was over 90% in the initial epizootic, but much less in the later episodes. In other areas, the effect of RCD has not been obvious (Table 4).



Based on data supplied by Centralian Land Management Association and Parks and Wildlife Commission of the Northern Territory

Figure 4. Rabbit numbers during initial RCD epizootics, Erlunda, Northern Territory.



Based on data supplied by Dr Glen Saunders, New South Wales Agriculture

Figure 5. Rabbit numbers during initial RCD epizootics, Central Tablelands, New South Wales.

Australia's wild rabbit populations also support a number of predators, both imported and native. The major imported predators are feral cats and foxes, and the major native predators are dingoes and birds of prey. Studies at two sites have shown that feral cat numbers have declined as rabbit have become less common, with some evidence that a similar fate met foxes. There has been some concern that the breeding of birds of prey would be affected by RCD, as was reported with myxomatosis in 1951 (Olsen and Marples 1992), but successful breeding of wedge-tailed eagles has been reported from at least one site.

Most of the benefits reported from the decline in rabbit populations are from the Flinders Ranges where RCD has been active for the longest. In that area, where rabbit numbers remain low, the recruitment of some native plant species, low bluebush (*Maireana astrotricha*), mulga (*Acacia aneura*), narrow-leafed fuchsia-bush (*Eremophilia alterniflora*) and miljee (*Acacia oswaldii*), regeneration of bullock bush (*Alectryon oleifolius*) and emu bush (*Eremophilia longifloria*) and recovery of needlewood (*Hakea leucoptera*), quandong (*Santalum acuminatum*), and maireana and acacia species have occurred. Other reports from the Kinchega National Park in New South Wales are of regeneration of purple wood (*Acacia carnei*), rosewood (*Alectryon oleifolius*), and belah (*Casuarina cristarta*) (Anononymous 1997). Given the ability of rabbits to damage even mature vegetation, the long-term survival of this vegetation will depend on the length of time the rabbit populations are held low. In contrast, the Coorong in South Australia has had low rabbit populations for over a year due to RCD, but no signs of regeneration of a specific species, sheoak (*Allocasuarina verticillata*) have been found. In other areas of Australia, such as Hattah in Victoria and Erldunda in the Northern Territory, seasonal and rainfall events are thought to be more important for plant growth and regeneration (Anonymous 1997).

To study the impact of RCD, and to determine how it can best be used by land managers for rabbit control, the governments established two complementary programs; the epidemiology program to study the disease and its transmission and a National Monitoring and Surveillance program to track the spread of the disease and study the impact on rabbit populations and on agriculture and the environment. The National Monitoring and Surveillance Program has more than 60

Table 4. Results of RCD releases in Australia.

State/Territory	Number of Release Sites	Obvious* RCD Activity	No Obvious RCD Activity	RCD Activity Not Known
Australian Capital Territory	8	2 (25%)	3 (38%)	3 (38%)
New South Wales	485	269 (56%)	132 (27%)	84 (17%)
Northern Territory	9	2 (22%)	5 (55%)	2 (22%)
Queensland	83	25 (30%)	5 (6%)	53 (64%)
South Australia	28	--	--	28 (100%)
Tasmania	15	1 (7%)	--	14 (93%)
Victoria	116	67 (58%)	31 (27%)	18 (15%)
Western Australia	41	11 (27%)	16 (39%)	14 (34%)
Total	785	377 (48%)	192 (24%)	216 (28%)

*Obvious RCD activity indicates that observant visitors to the area would be aware of significant rabbit deaths associated with RCD activity in the area.

Source: RCD Monitoring and Surveillance Program, State and Territory vertebrate pest agencies.

study sites across the country. The program is run by State and Territory pest control agents, with results collated nationally by the Bureau of Resource Sciences.

WHAT IS THE FUTURE OF BIOLOGICAL CONTROL, PARTICULARLY FOR VERTEBRATE PESTS?

The use of biological control for weeds in Australia continues, with two more weed species currently being considered for biological control. Research into fertility control of vertebrate pests, including mice, rabbits, and foxes, by a self replicating biological control agent which sterilizes the host continues. The proposed biological control agents are viruses, which can be species specific, and they will be genetically modified to cause sterility. Myxoma is the virus chosen for rabbits, but finding one specific to foxes is more difficult. This research is novel, but carries a high risk of failing to produce a suitable, effective agent.

New Zealand is also pursuing biological control of possums by searching for viruses in the possums native habitat, Australia; using a virus isolated in New Zealand (Wobbly Possum Syndrome Virus), possibly genetically modifying it; and virally vectored sterility.

IS RCD AN EFFECTIVE BIOLOGICAL CONTROL?

Generally RCD is considered effective, but how does RCD rate against the principles detailed earlier for biological control agents? Spreading RCD has been found to be technically possible, although research into less expensive, simpler techniques continues. RCD has been effective in reducing some rabbit populations drastically, with the effects lasting for at least two years. Since the long term impact of RCD on the environment and agriculture is not known, it is difficult to judge now the economic impact of RCD. Political acceptability was found with the unanimous support for use of RCD in Australia of Commonwealth, State, Territory and New Zealand Agriculture and Resource Management Ministers, and bipartisan support at the Commonwealth level. The public comment in Australia strongly supported the use of RCD. Early reports of regeneration, recruitment, and recovery of native vegetation are promising, although it is too early to detect the long-term effect on the environment. However, the long-term risk to the predators of rabbits, and through them to native animals, was considered during the assessment as much less than the possible long term benefit if the damage rabbits cause is reduced.

CONCLUSION

In Australia the technical feasibility and practicability of biological control agents tends to be well assessed. The escape of RCD from island quarantine experiments highlights both the problematic nature of biosecurity under field-relevant conditions and the difficulty of determining precisely how the agent will perform in the field. While all aspects of safety can be directly assessed before release, efficacy assessments are necessarily indirect.

When there is public concern, a legislative mechanism to test social and political acceptability is available and was used with RCD. Rabbit calicivirus has been active in Australia since November 1995.

The impact on rabbit populations has generally been spectacular in arid and semiarid areas, and more variable in wetter areas of Australia. Early reports of regeneration of native flora and declines in introduced predators are promising, although it is too early to determine the long-term benefit to native fauna and flora.

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RISK ASSESSMENT FOR IMPORTING AND KEEPING EXOTIC VERTEBRATES

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ABSTRACT: Exotic animals can establish wild populations that may cause serious adverse economic and environmental impacts. In Australia, there are a number of species currently kept in captivity that would pose such threats were they to escape and establish. Paradoxically, there is a push to allow freer trade in animals between countries for recreational and commercial purposes. This paper considers approaches to assess and manage these risks, including the application of ecological theory to estimate the probability of escape, establishment, eradication, and harmful impact. Although some potential forms of impact are obvious, particularly for species that are pests in their natural or introduced range, others may be less so because species may change their behavior or ecology in new environments, and interact in unpredictable ways with resident plant and animal species. This uncertainty creates a need to leave a wide margin for error when assessing the risk of harmful impact.

KEY WORDS: exotic species, risk assessment

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INTRODUCTION

Australia is a geographically isolated continent with a rich diversity of indigenous flora and fauna. The diversity of flora and fauna was even greater 200 years ago before European settlement and consequent habitat modification and ecosystem imbalance through the introduction of new species.

The development of agriculture in Australia relied on the introduction of many exotic agricultural plant and animal species—some of which subsequently established widespread wild populations and became pests including goats, pigs, and a wide range of weed species. European rabbits (*Oryctolagus cuniculus*) were brought in with the first European settlers for food, fur and skins and have subsequently become Australia's most widespread and significant pest animal (ABS 1996). The rate of spread of the rabbit in Australia was the fastest of any colonizing mammal anywhere in the world—advancing at up to 100 kilometers per year in the rangelands. The scale of the impact of the rabbit in Australia is considered to be unique in the history of wild animal introductions (Williams et al. 1995).

Other exotic species which have subsequently become pests were brought in as companion animals (e.g., cats), for sporting purposes (e.g., the European red fox—*Vulpes vulpes*), or simply to make Australia seem more "European" (e.g., the European starling—*Sturnus vulgaris*). Other species were, ironically, brought in to control existing pests and became pests themselves (e.g., the cane toad—*Bufo marinus*)(ABS 1996).

The result is a suite of introduced species—about 20 mammals, 30 birds, 20 freshwater fish, several amphibians, 500 invertebrates and 1,500 plants—which are pests of agriculture and/or the environment (ABS 1996). Hindsight provides the opportunity to prevent additions to this extensive inventory of pests. Risk assessment provides a mechanism.

Risk assessment processes for importing and keeping exotic vertebrates have an important role to play in reducing the likelihood of new species establishing and causing adverse impacts in Australia.

THE RISK

Species' translocations are proceeding at an unprecedented rate around the world and have the potential to cause adverse impacts to agricultural, environmental, and urban systems. There is a risk that new imported species, or exotic species that are currently kept in private collections and zoos, could escape and become pests. For example, the Somali dwarf mongoose (*Helogale undulata rufula*) is a small colonial carnivore that has significant potential to inflict damage to Australian wildlife if a wild population established. Yet a breeding colony of this species is kept in an open enclosure in an Australian zoo.

Ferrets have established wild populations in New Zealand and have had highly detrimental effects on wildlife. Yet ferrets can be kept without any permits or restrictions in Australia, and a wild population has now established in the Australian island state of Tasmania.

The forms of adverse impact that an established population of an escaped exotic animal could cause include:

- reduction of agricultural productivity (competition with grazing stock for feed and water, damage to horticultural crops, predation on stock, land degradation)
- environmental damage (competition with native species for food, water, and shelter
- spread of parasites or diseases
- attack, harassment, or annoyance threat to the community, particularly in the urban environment
- structural damage
- cost and collateral impact of control measures

THE BENEFIT

Exotic species can bring many benefits to agricultural production, recreation, tourism, scientific and medical research, international conservation efforts, and education. Many of Australia's agricultural and recreational industries are based on introduced animals and there is ongoing demand to import new species and genotypes.

A number of zoos in Australia are involved in coordinated breeding programs for endangered species, both for release programs and to maintain the genetic integrity of zoo populations. The display of such species also serves to educate the public about environmental and biodiversity issues.

THE ISSUES

Key issues relating to assessing the risk of importing and keeping exotic vertebrates are:

- What is an acceptable level of risk relative to potential benefits for the import and keeping of exotic species?
- How can we minimize risk exposure (i.e., controlling the number and type of exotic species imported in the country) and manage the risk that we accept (i.e., management of the species that are introduced)?
- What criteria can be used to assess the potential costs and benefits of importing and keeping exotic species in Australia?

This paper describes the regulation of exotic animal imports in Australia and outlines the risk assessment approach developed by Bomford (1991) that is currently used in Australia.

REGULATION OF EXOTIC ANIMAL IMPORT AND KEEPING IN AUSTRALIA

Legislative control over the import of exotic animals is held jointly by the peak Federal environmental agency—Environment Australia and the Australian Quarantine and Inspection Service (AQIS). Both organizations rely on advice on the "pest potential" of species from a national Vertebrate Pests Committee (VPC) whose members represent relevant State and Federal government agencies.

Until 1991, VPC, Environment Australia, and AQIS had no framework or guidelines for assessing the risks associated with the import and keeping of potential vertebrate pest species in Australia. Risk assessments were made in a fairly subjective way and were difficult to justify if political pressure was brought to bear to alter a decision.

Bomford's 1991 model was developed on the premise that the import and keeping of exotic vertebrates should be subject to a balanced and rigorous risk assessment, taking into account both potential benefits and harmful impacts, and using all available scientific theory and information on the biology of the species being assessed. It should be emphasized that, given the uncertainty of the assessment due to incomplete information, it is a predictive model rather than an absolute measure of risk. Thus, a conservative approach should be adopted along the lines of the precautionary principle: "the absence of evidence of risk does not equate to the evidence of absence of risk" (Moller and Barret 1996).

It is likely that community demands and international obligations under WTO agreements concerning free trade will result in increasing numbers of species being imported into and kept in Australia.

Thus, there is a need to develop transparent, evidence-based risk assessment processes to increase decision-making objectivity and reduce the influence of social, economic, and political pressures. Risk assessment processes should be developed in conjunction with interest groups to achieve transparency and enhance compliance, although the assessment itself should be entirely independent of these groups. Interest groups should pay for the application of the risk assessment process in accordance with the user-pays principle (AQIS 1991).

Rigorous risk assessment processes do not necessarily hamper free trade. Experience in Australia with weed risk assessment has shown that more scientific risk assessment models have the potential to prevent the entry of a greater proportion of high risk species while at the same time freeing up trade at the lower risk end to the extent that more plants could be imported (Walton and Ellis 1997).

Freer trade may also reduce risk by reducing illicit trading. For example, the Australian Quarantine and Inspection Service ended a ban on avian imports in 1989 to reduce the incentive to smuggle birds and eggs into Australia and, therefore, reduce the likelihood of introducing exotic avian diseases (Wilson 1988).

It is essential to get the risk assessment process right at the import stage, because once permission is given to allow a species into the country, it is extremely difficult to reverse it. Animal confiscations and increased keeping restrictions are often politically unpalatable and strongly resisted by keeper groups. Unfortunately, Australia is already faced with the situation where high risk species (e.g., Indian ringneck—*Psittacula krameri krameri*, monk parrot—*Myiopsitta monachus*, and red-eared terrapin—*Pseudemys scripta*) entered the country before the current, more rigorous risk assessment processes, and some of these are now widespread through small private collections.

THE CURRENT RISK ASSESSMENT PROCESS

Ecological theory relating to each of the component processes associated with exotic species introductions are considered by the current risk assessment model used in Australia. The component processes are the probability of:

- an exotic species escaping
- the escapees establishing a wild population
- the escapees or established population being eradicated
- harm associated with the three former factors outweighing the potential benefits associated with the species being imported

Probability of Escape

Clearly, some species possess attributes that enhance their ability to escape. Security of premises and keeping restrictions can be used to manage this risk. However, no physical barriers are completely proof against:

- natural disasters such as floods, cyclones, fires and earthquakes
- willful removal by animal liberation groups or illegal traders
- vandalism, terrorism, civil unrest or war

There are numerous examples of exotic species being released during natural disasters. For example, a flock of yellow-headed Amazon parrots (*Amazona ochrocephala*) was released by a California aviculturist when fire threatened his collection, resulting in the establishment of an exotic population (Long 1981; Nilsson 1981).

Probability of an Escaped Population Becoming Established

There is a large body of scientific theory on the factors that affect establishment, including analyses of previous successful and unsuccessful introductions. This information was used in Bomford's (1991) model to draw generalizations about factors that affect the probability of establishment. These include:

Escape conditions:

- timing of escape—especially season
- number of animals escaped—critical threshold usually about 20 individuals
- sex of animals escaped—single sex collections reduce the risk of establishment
- condition of escaped animals—particularly their health, sex and reproductive status
- source of escaped animals—wild caught from expanding populations most successful

Environmental factors:

- bioclimatic distance—Nix and Wapshere (1986) found bioclimatic distance, which is a measure of climatic similarity between the sites of origin and release based on rainfall and temperature, accounted for 80 to 90% of the variance in success of introductions of birds into Australia
- site—factors conducive to establishment include: the availability of habitat near the release site that meets the species' physiological and ecological needs, disturbed habitats, and absence of competitors or predators

Community attitude:

- likelihood of the public reporting escapes which would allow early detection, capture, and eradication
- likelihood of the public feeding and sheltering escapees which would increase probability of establishment

Species attributes:

- distribution—species that are widespread and abundant in their natural range, and/or have a history of establishing exotic populations represent a higher risk
- physiology—species that have the ability to tolerate a wide habitat and climatic variability and have a high reproductive rate (early sexual maturity, large clutch/litter size, high breeding frequency, short gestation and opportunistic breeding) represent a higher risk
- diet—dietary generalists and opportunists are more successful than specialists, and herbivores are more successful than carnivores or omnivores
- behavior—characteristics increasing the risk of establishment include: commensalism with people or ability to live in modified environments, ability to seek out habitats suitable for survival, vagility (ability to change domicile over time), non-migratory, and/or flocking or herding behavior
- phenotype and genotype—high variability increases the potential for rapid adaptive radiation

Although the species attributes that favor establishment are represented in the exotic species which have established wild populations in Australia, there are many exceptions. There has been little research to identify or quantify the relative significance of these attributes or how they might interact—so the theory is far from robust or definitive.

The degree of certainty in assessing the likelihood that a species could establish a new environment is limited, particularly by:

- the large number of factors that influence success, including a high element of chance
- inadequate information on the ecology, physiology and behavior of most species, and the cost and long-term nature of research needed to obtain these data
- unpredictability with which species may change their ecology, behavior, phenotype or genotype in new environments, especially where there are different foods and fewer predators, competitors and diseases

The existence of escape contingency plans that enhance early detection and capture/eradication influences the probability of establishment, and may be taken into account in the risk assessment process.

Probability of an Escaped Population Being Eradicated

Once a population is established, eradication chances are likely to be low or non-existent due to high costs, lack of political will and, for many species, the extreme difficulty of the task. There are no cases of an established mainland pest population ever being eradicated on any continent. It is, therefore, critical that there are contingency plans and associated resources for early detection and eradication of newly escaped individuals or small localized populations that become established.

Species attributes that affect the chances of early detection and eradication include visibility, habitat preferences, behavior, and susceptibility to trapping or poisoning.

The feasibility of eradication will also depend on community attitudes towards the species involved and the control measures used.

Probability of Net Adverse Impact

For an assessment of potential environmental and agricultural damage, it is necessary to predict probable population densities and distributions.

Analysis of trends in past introductions enable generalizations about taxa and species attributes that cause environmental or agricultural damage.

Ebenhard (1988) reviewed the literature on introductions of exotic vertebrates worldwide and found that 40% of mammal introductions have been linked to some ecological impacts on populations of native plants or animals, mainly through predation, competition, or habitat damage. Ebenhard found of the 49 recorded introduced predatory mammal species, 20 are reported as having caused one or more indigenous populations to decline in abundance or become extinct.

In comparison, Ebenhard found only 5% of bird introductions have been associated with ecological impacts, but considered this may be a great underestimate. The main effects of introduced birds are as competitors with native species and as vectors or reservoirs of disease. These effects are hard to demonstrate and poorly documented. Exotics may also hybridize with native species corrupting their gene pool. Waterfowl are particularly susceptible to this problem.

Estimated adverse impact is weighed against estimated potential benefits. As indicated previously, potential benefits may be significant and justify some risk of harm.

APPLICATION OF THE RISK ASSESSMENT MODEL

The VPC currently lists exotic species in one of five categories:

Category 1 - entry and keeping prohibited
Category 2 - restricted to high security collections
Category 3 - other collections
Category 4 - entry and keeping unrestricted
Category 5 - pests already widespread

Applications are made to VPC by public and private zoos and individual keepers to downgrade category listing for species that they want to import, or species that are already in Australia but that they want to keep in a lower security collection.

Because pest species do not respect state borders, it is essential that uniform risk assessment processes operate within all states of a country. In Australia this is effectively achieved through the national VPC, although individual states are currently able to allow a species to be downgraded one category level from the national recommendation.

The risk assessment model developed by Bomford (1991) is used to determine whether the benefits of recategorization applications outweigh the risks.

Although there has been a trend towards more quantitative risk assessment models in the last decade, most biological risk assessments are going to be semi-quantitative at best due to incomplete information. One advantage of semi-quantitative or quantitative risk assessment is that they allow sensitivity analyses to determine the most critical points of risk or risk factors. At the same time, quantitative risk assessments may be misleading if they suggest a level of accuracy which is not supported by available data (Nunn 1997).

The Bomford (1991) model is qualitative because it was considered that with current levels of knowledge, numerical models would give a misleading impression of objectivity, and would probably have a low level of accuracy. VPC is currently considering the possibility of quantifying the model. One way of doing this would be to consider the animals that have been introduced to Australia in the past and compare the attributes of those that have established compared to those which have not. Of those that have established, the attributes of species that have become widespread and/or caused damage can be considered. In this way, numerical values can be applied to species attributes depending on the degree to which they are likely to confer higher risks of escape, establishment and damage. The model might then be tested against future introductions and refined as appropriate. However, no model will be absolute, due to the influence of chance factors—particularly environmental conditions at the time of escape.

The current model used by AQIS to assess the weed potential of imported plant material is semi-quantitative. It overcomes some of the problems of using quantitative models by including a large number of questions (49), and a character that reduces the effect of assessor subjectivity by reducing the weighting of any one question on the final score. The model does not require that all questions are answered, recognizing that information on a particular species may be incomplete (Walton and Ellis 1997).

An example of the application of the exotic species risk assessment process used in Australia is the recent rejection of an application to import the rock hyrax (*Procavia capensis*). The rock hyrax is a rodent that is considered hard to contain and has a number of features that indicate a high risk of rapid establishment and spread and the possibility of agricultural and environmental damage, including:

- small, fast-moving and secretive—making early detection and eradication to prevent establishment difficult
- high reproduction and dispersal rates and opportunistic feeders giving a high probability of establishment
- potential for large distribution and abundance of an established population, coupled with opportunistic feeding behavior providing a high probability of environmental and agricultural damage

Given that there were few benefits to be realized from importing these species, the decision to reject the import proposal was clear-cut.

A less clear-cut case where an import application was rejected was for the blackbuck antelope (*Antilope cervicapra*) in 1990. This species has the potential to be both a pest and a new commercial livestock species. It has attributes that would make it relatively easy to eradicate escaped individuals or a small localized population. These include its preference for open habitat, low dispersal rate, low rate of increase, and herding behavior. However, the blackbuck's appealing appearance could cause public resistance to control by shooting or poisoning and would reduce the probability of eradication of an escaped or established population. The Bomford (1991) model took into account all of this information and the application was rejected.

Linked to the recategorization process are assessments for "Approved Collection Status" (ACS) to allow a particular institution to keep a species. This takes into account the security, credentials and financial viability of the proponent organization. It also takes into account how conducive the surrounding environment is likely to be to establishment of the proposed species.

An example of the need for the ACS process is the situation of Tipperary Sanctuary in the Northern Territory of Australia. This was established in the 1980s by a wealthy English businessman who wished to keep a wide range of rare species in a remote location surrounded by bushland and subject to monsoonal rain and cyclones. Despite the fact that the surrounding environment and remoteness would make detection and eradication of escaped animals difficult, the Sanctuary was approved and a few years later had 1,500 animals in a 1,000 hectare area.

The Sanctuary contained a number of exotic ungulates, despite the fact that at about this time there was a campaign in the region to eradicate unmanaged ungulates (including feral horses and donkeys and water buffalos) to help eliminate brucellosis and tuberculosis from stock. Adding to the threat, the Sanctuary encountered financial difficulties in 1990 to the extent that there were problems in providing food for the animals and it would have been difficult to find alternative homes for the animals at short notice. The peak zoo body in Australia has since developed a contingency plan for relocation of any unwanted animals.

Although VPC has a reasonably close relationship with the larger zoos and wildlife parks in Australia, the status of animals held in the large number of smaller collections is less certain. Many species—particularly birds—have been imported into Australia under previous, less rigorous risk assessment processes. The large recreational avicultural industry in Australia also provides a market for illegal smuggling. It is difficult to manage such a diffuse menagerie of animals with regard to knowing what animals are kept, how they are kept, and if there have been transfers or escapes. Thus, private collections pose one of the greatest risks and the biggest challenge of risk management of exotic vertebrates.

CONCLUSIONS

General principles of risk assessment include:

- models need to be scientific and evidence-based—more quantitative models can increase objectivity if adequate information is available to support this approach
- there is some risk associated with all exotic animal imports—scientific risk assessment processes allow the free trade:risk balance to be optimized
- the degree of certainty in assessing whether a species could establish in a new environment and inflict damage is greatly limited by a lack of data and the ecological theory—be conservative if data inadequate
- models should be continuously evaluated for predictive accuracy and modified as better information becomes available
- new models can be used to conduct retrospective analyses on exotic species being kept on the basis of previous assessment processes
- detailed contingency plans for early detection and eradication of newly escaped individuals or localized established populations reduce the risk and could be taken into account in the risk assessment process
- because there can be no guarantee that escape can be prevented or eradication will be possible, species considered to pose a high risk should be prohibited even if they represent significant potential benefit.

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COMPARISON OF WHITE MINERAL OIL AND CORN OIL TO REDUCE HATCHABILITY IN RING-BILLED GULL EGGS

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ABSTRACT: Oiling eggs is a potential management method for controlling nuisance or depredating populations of ring-billed gulls, Canada geese, and other bird species. However, no registration for an oiling compound currently exists with the Environmental Protection Agency. Efficacy data were collected for white mineral oil and corn oil to reduce the hatchability of ring-billed gull eggs. Egg failure was 99% in corn oil, 96% in white mineral oil, and 35% in control eggs. Most treated eggs that hatched were treated early in the incubation period, 1 to 8 days after clutch completion. A Wildlife Service Technical Note on the use of corn oil as an oiling agent is now available.

KEY WORDS: *Larus delawarensis*, corn oil, egg oiling, reduce hatchability, registration, ring-billed gulls

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INTRODUCTION

Egg addling (including shaking, freezing, removal, destruction, puncturing, and oiling) is among several techniques to manage bird populations such as Canada geese (*Branta canadensis*) and gulls (*Larus* spp.) that are implicated in agricultural crop damage, health and safety problems, and nuisance concerns (Laycock 1982; Christens and Blokpoel 1991). One advantage of oiling over other techniques is the incubating birds continue to incubate eggs past the normal hatching time, which precludes renesting (Christens and Blokpoel 1991). For example, Canada geese will incubate their nests from 1 to 30 days beyond the expected hatching date ($\bar{x}$ = 14.2, SD = 10.3 days; Cummings et al. 1997). Further, egg oiling is more socially acceptable than destroying adult Canada geese (Laycock 1982). For example, a survey of Washington residents indicated no opposition to a Canada goose egg oiling program in the Seattle area (Pitzler, USDA, APHIS, Wildlife Services, pers. comm.).

In laboratory and field tests, white mineral oil (Daedol® 50 NF; Daminco, Inc., Mississauga, Ont., Can.) has been used successfully as an egg treatment to almost completely suppress hatchability of chicken, ring-billed gull (*L. delawarensis*), herring gull (*L. argentatus*), and Canada goose eggs (Blokpoel and Hamilton 1989; Christens and Blokpoel 1991; Christens et al. 1995; Cummings et. al 1997). One advantage of using white mineral oil is that it is chemically inert, nonpoisonous, highly purified (100%), and would not create an environmental hazard (Christens and Blokpoel 1991).

There are no oils, including white mineral oil, registered as an egg addling treatment in the United States. Registration of an oiling compound is a requirement for egg oiling to be used as part of a management program. Currently, oil applications used for egg addling fall under Environmental Protection Agency (EPA) guidelines that permit only treatment of <4 ha of nesting area. In 1994, the EPA announced that it was proposing to deregulate several types of "food" oils from the formal registration process (Federal Register 1994). The substances listed would not need to be registered as long as the mode of action of the pesticide was considered non-toxic. However, laboratory and field efficacy data needed to be collected to fulfill registration requirements. The authors have tested food oils (corn, castor, linseed, safflower, and soybean) in incubator tests to determine their effectiveness in reducing hatching success in chicken eggs (Pochop et al. 1998). All five oils were as effective as white mineral oil. Corn oil was selected for field efficacy tests based on its low cost, ease of application, and availability in most areas. In this study, the authors compared the effects of white mineral oil and corn oil on hatchability of ring-billed gull eggs at Cabin Island, Grant County, Washington.

STUDY SITE

The study was conducted on Cabin Island which is located on the Columbia River about 1.5 km north of the Priest Rapids Dam. It is estimated that up to 3,600 ring-billed gull nests on about 4 ha of the 30-ha island.

METHODS

The study was conducted from May 6 to June 13, 1995. Follow-up data was collected May 7 to 21, 1996 and May 6 to July 2, 1997.

In 1995, ring-billed gull nests having ≥3 eggs were selected for this test. A numbered survey stake was placed next to each nest. A 6-l hand-held sprayer was calibrated to deliver white mineral oil at approximately 6 ml/sec at 10 psi and corn oil at approximately 6 ml/sec at 15 psi. Eggs in each nest were sprayed with 2 ml of assigned oil per egg. This amount was adequate to completely coat the egg. During treatment, the tip of the sprayer was held about 5 to 10 cm from each egg. Control eggs were left untreated. The authors randomly selected 319 ring-billed gull nests for the test and randomly assigned 29 as control, 139 as white mineral oil, and 151 as corn oil treatments. The minimum number of control nests needed for the statistical analysis were used because, in addition to collecting efficacy data on white mineral oil and corn oil, the authors were interested minimizing the number of young reared on the island. About 20% of the eggs were treated 1 to 8 days after clutches were completed and the remaining eggs were treated 9 to 15 days into incubation. Eggs were visually checked for signs of hatching 5, 6, 20, and 39 days post-treatment.

The hypotheses for both eggs and nests were: control hatching success was the same as the treatments, and corn oil hatching success was the same as white mineral oil. The hypotheses were tested using Chi-square analysis. Eggs that failed were the total of all eggs that failed. Nests that failed were defined as nests that had no eggs hatch.

On May 5, 1995, the rest of the nests on the island were treated (estimated 2,900 nests with ≥1 egg) with either white mineral or corn oil. These nests were not used in the comparison of white mineral oil and corn oil hatching suppression but were treated to control the fecundity of ring-billed gulls on the island. On the June 13, six transects (~80 to 120 m long, ~2 m wide) were walked and the number of nests and young present along the transects were recorded.

On May 7, 1996 and May 6, 1997, the authors went to the island to conduct an initial oiling of all nests in the colony with corn oil. Because the sprayer parts were starting to wear out by 1996, the pressure gauges were no longer able to be used as a reliable measurement of oil output for the field. Therefore, the authors pumped the sprayers until the oil sprayed rather than streamed out of the sprayer. It was assumed that the spray of oil was achieving the goal of a 6 ml/sec. application rate. However, that rate was probably being exceeded. The authors returned on May 21, 1996, May 21, 1997, and June 9, 1997 to re-oil all nests and determine hatching success. The number of nests and eggs on these visits were recorded as nests were treated. In 1996, no follow-up visits were conducted after May 21 because inclement weather prohibited travel to the island. In 1997, the colony was visited on July 2 to determine if any further hatching occurred in nests.

RESULTS

Egg failure was 99% with corn oil, 96% with white mineral oil, and 35% with control eggs (Table 1). Corn oil was more successful than white mineral oil in reducing hatching success in eggs ($\underline{F}_{1,2}$ = 9.371, $\underline{P}$ = 0.002). All of the corn oil and 90% of the white mineral oil treated eggs that hatched were treated early in the incubation period, 1 to 8 days after clutch completion. Hatching suppression island-wide for eggs in 1995 was 96% (corn and white mineral oil), in 1996 (corn oil only) was 99.7%, and in 1997 (corn oil only) was 99.6%.

Nest failure was 97% in corn oil, 88% in white mineral oil, and 10% in control nests. Corn oil was more successful than white mineral oil in reducing hatching success in nests ($\underline{F}1,2$ = 8.761, $\underline{P}$ = 0.003). Hatching suppression island-wide for nests in 1995 (corn and white mineral oil) was 95%, in 1996 (corn oil only) was 99.5%, and in 1997 (corn oil only) was 99.3%.

On June 13, 1995, May 21, 1996, and June 9, 1997, gulls were still engaged in nesting activities. By July 2, 1997, the island was essentially abandoned for the nesting season. Only four adult gulls were observed near the island. There were no eggs in nests and only egg fragments were observed.

Table 1. The effectiveness of white mineral oil and corn oil on hatchability of ring-billed gull nests and eggs, May 5, through June 13, 1995, Cabin Island, Grant County, Washington.

	Total No.		Eggs/Nest	% Failed (No.)	
Treatment	Egg	Nests	($\bar{x}\pm$s.e.)	Eggs[1]	Nests[2]
Control	89	29	3.1±0.05	35 (31)	10 (3)
White Mineral Oil	429[3]	139	3.0±0.02	96 (410)	88 (123)
Corn Oil	458[4]	150	3.0±0.02	99 (453)	97 (146)

[1]For all white mineral and corn oil eggs that failed to hatch, $\underline{F}_{1,2}$ = 9.371, $\underline{P}$ = 0.002.
[2]In white mineral and corn oil nests where all eggs failed to hatch, $\underline{F}_{1,2}$ = 8.761, $\underline{P}$ = 0.003.
[3]Nine additional eggs were observed in the nest after initial treatment and were figured into the results.
[4]Six additional eggs were observed in the nest after initial treatment and were figured into the results.

DISCUSSION

Hatching suppression for both oils in the study was similar to other field egg oiling studies; 97-100% on ring-billed gulls and 100% on Canada geese (Blokpoel and Hamilton 1989; Christens and Blokpoel 1991; Christens et al. 1995; and Cummings et al. 1997). However, corn oil was more effective than white mineral oil in suppressing hatching success in this study and it is unclear why this would occur in the field. There were no differences observed in the laboratory (Pochop et al. 1998). It is possible that some characteristic(s) of the corn oil are more resistant to weathering such as a higher viscosity or a slightly longer drying time than white mineral oil. Advantages of corn oil over white mineral oil for field use include; corn oil ($2.10/l, 100% pure) costs less than white mineral oil ($8.45/l, 100% food grade) and is readily available in various quantities throughout the United States.

Egg oiling studies in gull colonies suggest that timing is crucial to reducing egg hatchability. Only oiled eggs that were treated early in incubation (1 to 8 days) hatched in this study and was observed in other studies (Blokpoel and Hamilton 1989; Christens and Blokpoel 1991). However, because nesting in gull colonies can be asynchronous, timing of clutches for operational sprays must be closely monitored. Christens and Blokpoel (1991) offer suggestions on timing of operational sprays to minimize the number of sprays needed for hatching suppression.

Concern exists that nesting birds will remain on their nests too long if the eggs are oiled potentially resulting in starvation (Draft Environmental Assessment, Canada Goose Population Management in Anchorage, Alaska, unpublished report September 1997). However, ring-billed gulls left the island in this study by July 2, 1997. No dates are available for 1995 or 1996, but lower numbers of eggs per nest on the early May visits compared to site visits two weeks later indicated that clutch completion occurred later in 1997 (unpublished data). Ring-billed and California gulls will fledge broods hatched in early June by mid July and clutches can be hatched as late as the end of June (Vermeer 1970). The presence of chicks appears to be the primary reason adults remain on nesting grounds (Vermeer 1970). In the case of Canada geese or other bird species where concern exists that they may remain in an area too long, removal of oiled eggs after laying ceases may encourage the birds to move out of the area reducing the potential for negative impacts of egg oiling.

On March 6, 1996, the EPA published in the Federal Register a notice exempting certain materials from regulation under Section 25(b) of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), as amended. This notice allows corn oil to be used without EPA regulation as long as the uses meet certain qualifications: they are not related to public health, efficacy data are available, and certain labeling requirements are met. The data collected in the authors' incubator study (Pochop et al. 1998) and in this study satisfy the laboratory and field efficacy data requirements for corn oil. A Wildlife Service Technical Note on the use of corn oil as an oiling agent is now available.

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BARN OWL NEST BOXES OFFER NO SOLUTION TO POCKET GOPHER DAMAGE

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ABSTRACT: The belief that native predators such as barn owls (*Tyto alba*) keep native rodents such as pocket gophers (*Thomomys* spp.) in check has a long history, in spite of a lack of evidence that such predators play any role in lowering pest rodent populations to the extent that their pest status is measurably influenced. Attempts to artificially increase native predators such as barn owls in the hope of increasing predation on native pest rodents is not new and has been explored many times in the past, but as yet evidence of success is absent. Since predation is a slow ongoing process, two biological principles work to nullify any negative effect on populations of rodents with high reproductive propensities. The belief that predators somehow control their prey is challenged as a biological control approach, and proven gopher management methods offered in its place.

KEY WORDS: barn owls, *Tyto alba*, pocket gophers, *Thomomys* spp., gopher control, biological control, predator/prey relationships

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INTRODUCTION

It is a long standing misconception that native vertebrate predators, such as barn owls (*Tyto alba*), will assist in controlling pocket gophers (*Thomomys* spp.) and other native rodents to below damaging levels. In recent years, there has been a resurgence in the perpetuation of this myth as orchardists and vineyard managers are being misled into believing that if they install barn owl nest boxes on their property their pocket gopher problems will be resolved. The truth is that no scientific evidence exists to support this belief. Those promoting the establishment of barn owl nest boxes as a biological control technique overlook certain fundamentals in predator/prey relationships and the complex interactions and feeding strategies among all the other predators present. Also overlooked are the reproductive potential and the general population dynamics of the most prevalent small rodents of the region. To suggest that the installation of barn owl nest boxes and the hoped-for ensuing increase in barn owls will assist in gopher control, ignores the fact that rodent species have evolved in the presence of these native predators and, thus, have reproductive capabilities to more than compensate for those killed by predators; hence, rodents are very capable of maintaining thriving populations.

ABSENCE OF EVIDENCE

To support their contention, those who promote the barn owl nest box concept for gopher control often provide misleading and grossly biased evidence which, without close scrutiny, may sound very convincing. Some point to previous dietary studies, while others are involved in collecting the regurgitated pellets from within or beneath the nest boxes. These are then teased apart in order to identify and count the rodent skulls and determine the content of the owl's diet. From such studies, calculations and extrapolations are made as to how many rodents are consumed by a pair of barn owls over the course of a year. If conducted with a large enough sample over a period of several years, this will provide useful data about food habits but nothing more. Such an analysis does not furnish evidence on the effects of owl predation on populations of pocket gophers and the other rodent species found in the owl's diet because information on the number of pocket gophers or voles (*Microtus* spp.) (the barn owl's primary food species) found within the foraging range is absent and has not been determined. Even if a pair of barn owls consumed 900 rodents annually, this has no significance if the number of breeding rodents available to these owls exceeds three million, and this three million is capable of producing nine to twelve million young annually.

EFFECTS OF PREDATION NULLIFIED

When promoters of this concept are challenged with these facts, they contend that because owls eat rodents they must provide some benefits to the grower. However, evidence suggests that predation probably helps the pocket gopher populations. Since predators tend to capture and kill a disproportionate number of the weakest and less agile, which often represents the diseased, deformed, or aging individuals, in addition to inexperienced and less alert young, this may, in fact, contribute to a more vigorous and thriving rodent population (i.e., the survival of the fittest). Natural predation, combined with mortality caused by diseases, parasites, social strife, and adverse environmental conditions, decreases competition among the surviving members. Not only will social stresses be diminished, but there will be less competition for the most nutritious food and, as a result, the reproductive potential for the remaining rodents of the population may be elevated (i.e., compensatory replacement).

NATURALLY OCCURRING PREDATION

Predation is an ongoing phenomenon with hawks, owls, fox, kit fox, coyotes, skunks, weasels, badgers, bobcats, raccoons, and snakes feeding upon pocket gophers in orchards and vineyards, as do domestic cats and dogs; hence, this fact is not in question. It is whether these predators can collectively kill sufficient numbers of pocket gophers to measurably reduce their population in any given area. It doesn't matter how many gophers are killed if the reproductive rate of pocket gophers has the potential to more than replace those losses. Many researchers have studied pocket gophers and their biology over the years, but none has concluded that predation plays any significant role in limiting their numbers.

TRADITIONAL MANAGEMENT IS ESSENTIAL

In spite of being preyed upon, certain rodent populations naturally exist in densities where they cause serious agricultural damage. A few pocket gophers in a newly planted orchard or vineyard can kill hundreds of trees or vines in a single year. Attempting to rely on barn owls, foregoing traditional proven gopher control management techniques such as poison baits or trapping, is inviting potential gopher problems which, if unchecked, may prove disastrous to the grower. Orchardists neglecting gopher control, in some instances, lose through root girdling as much as a third of their trees in the first two or three years.

Suggestions for the Grower Who Wants to Avoid Pocket Gopher Damage

1. Eliminate all or nearly all the gophers from the land prior to planting a new vineyard or orchard. This can be accomplished by planting crops which do not support pocket gophers for a few years prior to orchard planting. Alternatively, gophers can be controlled with strychnine baits dispensed by a hand probe or, in large fields, with the use of the mechanical burrow builder. The burrow fumigant, aluminum phosphide (a restricted use pesticide), although more expensive, can also be very effective, as can trapping. The latter two are more suited for the less dense populations and/or the smaller acreages.
2. Monitor newly planted orchards or vineyards monthly or bimonthly for evidence of fresh mounds, and carefully inspect trees or vines that are showing symptoms of stress. Initiate control as soon as gophers are discovered, for it is much more cost effective and environmentally sound to control gophers when they are at low levels.
3. Remember, gophers, when present, cause the most severe damage in years just following planting. Young trees and vines are most susceptible to injury because of their small diameter, permitting the gopher to easily completely girdle them within one night of feeding. As the trees or vines mature beyond four to seven years of age, gophers are less likely to completely girdle them, but a partial girdle or severe root pruning may slow growth or reduce crop production.

SUMMARY

Without supporting facts, it is time to abandon this erroneous belief that native predators, such as barn owls, can provide meaningful control of pest rodent species such as pocket gophers or voles. This does not imply that predators never have a regional impact on their prey, at least temporarily. A few predator/prey relationships such as the effects of mountain lions (*Puma concolor*) on bighorn sheep (*Ovis canadensis*) and wolves (*Canis lupus*) on caribou (*Rangifer tarandus*) are examples for which good evidence exists. Such examples, however, are specific and cannot be generalized to all predator/prey relationships.

WILDLIFE INFORMATION SOURCES AND SEARCH METHODS ON THE INTERNET

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ABSTRACT: Vertebrate pest damage information is pulled from a variety of disciplines ranging from wildlife management to psychology. The Internet has opened the door to what seems to be an unending number of information sources. Researchers can become overwhelmed by the choices and different levels of information available. The correct use of search engines and a checklist of criteria to evaluate the quality of information obtained can help to eliminate the extraneous information and make the time spent on the Internet more productive. There are a large number of wildlife, biology, environmental, and other related sites that are especially useful to the wildlife damage management community.

KEY WORDS: Internet, search engines, wildlife damage, information sources

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INTRODUCTION

Vertebrate pest control research, by its very nature, is an aggregate of numerous disciplines—wildlife biology, ecology, zoology, bioelectronics, chemistry, botany, computer science, psychology, statistics, etc. This mosaic makes the work fascinating—information is pulled from many of these disciplines to find solutions to pest control problems. But what makes it fascinating also makes finding the information difficult. The Internet provides access to thousands of web sites that support the wildlife damage community and makes them readily accessible to users around the world.

Access to the Internet

Obtaining an Internet account and password has become fairly straightforward even in remote areas of the world. Many companies and universities maintain Internet links that are available to staff. Internet service providers (ISP) are listed in the yellow pages under "Internet Products & Services" and offer a wide range of service options. Public libraries now offer Internet access to patrons and are also a good source for training classes and online help.

Search Engines and Directories

It is easy to be overwhelmed by the amount of information on the web. Using search engines properly will help to eliminate false leads and extraneous material. Over 260 search engines are indexed on My Virtual Reference Desk (http://www.refdesk.com) a web page that ties together all of the search and reference tools. True search engines like Hotbot, Alta Vista, and Northern Light scan the web for word or phrase matches that are identified by computer robots or spiders. These are computer indexing routines that index major words in a web page. Web directories like Yahoo! (http://www.yahoo.com), WebCrawler (www.webcrawler.com), or OpenText (www.opentext.com) are indexed by people who review the information and arrange it hierarchically (Lidsky 1997; Bell 1997). Yahoo!'s strength is in its content and coverage. If you are looking for the Colorado State University web page, Yahoo! indexes it under "Regional:U.S. States:Colorado:Education:College and Univerisities:Public." Hotbot (http://www.hotbot.com) is the most current search engine at the time of this publication, reindexing its database every two weeks. Hotbot allows you to use boolean logic and searches both the Web and Usenet which greatly expands its search results (Hock 1997). Special features include using a search modifier that searches for pages that have changed since you last used the program or within a specific time period, and the option to save searches for later use. Hotbot also has a great feature that lets you search to a specific depth in a page. This is important when you are digging for information that could be buried on the fourth level of a web page (Haskin 1997). Northern Light (http://www.northernlight.com) is the newest search engine on the web. Designed by librarians, it searches both the web and a database of more than 1,500 full-text journal titles. Search results are organized into folders that are sorted by subject, type, source, and language. A unique feature in Northern Light allows you to order any articles directly from them by e-mail for a reasonable cost (Notess 1998).

Separate news searchers are an excellent source for finding more up-to-date news stories in both regional, national, and international newspapers. They are updated throughout the day which puts them weeks ahead of regular search engines, and they focus specifically on news stories. Excite NewsTracker (http://nt.excite.com) has the most extensive and powerful news database with more than 300 publications indexed. NewsTracker has boolean searching and a special feature that tracks high-interest stories. Newsbot (http://www.newbot.com) is one of the more powerful news searchers currently available. Supplied by the Reuters News Service, Newsbot allows full-text searching of articles, customized user profiles, and free downloading of articles (O'Leary 1997b). Yahoo! and Infoseek also search the news wires on a more limited basis. Yahoo! stores articles for seven days, and InfoSeek does not have a browsing function which limits searching results.

Important information also lies with the personal knowledge and capabilities of biologists and technicians working in the field. Finding people on the web is easy using search utilities like WhoWhere (http://www.whowhere.com), InfoSpace (http://www.infospace.com) which will give you a map right to the location, and

Four11 (http://www.four11.com) which will make the telephone call if you have the equipment on your computer (Bell 1997).

Search Criteria

It is very easy to find information on the Internet. Unfortunately, many searches result in hundreds, if not thousands, of hits. The real trick is to find something that is relevant to your search topic. Listed below are some specific things you can do to make your search time more productive.

1) Be specific in your search and beware of search terms that may have a double meaning. Using the term "bears" will find articles on black bears and the Chicago Bears football team! *Urus americanus* will find sites directly related to the animal.
2) If you cannot be precise, use search engines like Northern Light or Infoseek that make it easy to refine your initial search.
3) Specialized search engines may give you better results than the big search engines.
4) Pick a search engine that you like and learn how to use it. Each product has special features and tools that make searching much more powerful (Haskin 1997).
5) Learn how to use Boolean logic—it will help in refining your searches. "Coyote and Yellowstone" will find hits that include both terms; "Coyote or Yellowstone" will find hits that have either term; "Coyote and Yellowstone not wolves" will find pages that include coyotes, Yellowstone, but not wolves.
6) Do broad searches using several search engines or a meta search engine that taps into a variety of sources.

As with all reference sources, you should rely on information from reputable sources. If you have a question about where something you found on the web came from, call the Webmaster to verify the source (Clark 1997).

Wildlife Damage Websites

Aquaculture. Aquaculture farms have grown in number over the past few years and have become an attractive food source for a variety of waterfowl. The National Agricultural Library's Alternative Farming Systems Information Center (http://www.nalusda.gov/afsic) has publications and links to aquaculture sites. AquaNIC (http://ag.ansc.purdue.edu/aquanic) and the California Aquaculture (http://aqua.ucdavis.edu/links/links/html) site include industry links, publications, management tips, and related information.

Bird/Aircraft Hazards. NWRC's Sandusky, Ohio field station (http://www.rbcg.com/nwrcsandusky) has been conducting research on bird aircraft collisions and is an excellent source for publications and links to other bird/aircraft sites. AirSafe.com (http://www.airsafe.com/birds.htm) includes links to articles about bird/aircraft strikes, airline information, and management documents. The Federal Aviation Administration (http://www.faa.gov/arp/hazard.htm) and Transport Canada (http://www.tc.gc.ca/aviation/aerodome/birdstke/main.html) are also rich sites for bird/aircraft information.

Wildlife Damage Links. The United States Department of Agriculture's National Wildlife Research Center (http://www.aphis.usda.gov/ws/nwrc) web page offers information on current Center research, publications, and contact numbers. You can contact the NWRC library directly for copies of all publications produced by Center scientists. The Jack F. Berryman Institute for Wildlife Damage Management (http://sticky.usu.edu/~cnr/fishwild/berry.htm) is the main web page for Utah State University's wildlife damage program. It links to Keeping Wildlife At a Safe Distance (http://cc.usu.edu/~schmidt/welcome.html), an excellent source for information on wildlife damage resources, government agencies, legislation, and how-to publications on wildlife damage. There is also a link to the Wildlife Damage Listserv. TEXNAT (http://texnat.tamu.edu/atexnat.htm), the Texas Natural Resource Web maintained by Texas A&M University focuses on natural resources in Texas. Information includes research and extension publications, management tips, educational programs, and symposium proceedings. Publications include the "Predation Guide" (http://texnat.tamu.edu/ranchref/predator), adapted from "Procedures for Evaluating Predation on Livestock and Wildlife" by Wade and Bowns, "Coyotes in the Southwest" and "Feral Swine: a Compendium for Resource Managers." North Dakota State University's excellent guide, "Prevention & Control of Wildlife Damage" can be found on the North Carolina Natural Resources webpage (http://www.ces.ncsu.edu/nreos/wild/wildlife.html). Rutgers' Cook College Wildlife Damage Control Center (http://cook-college.rutgers.edu/www/cent-inst/wildlife.html) lists faculty names and contact numbers. The Armed Forces Pest Management Board (http://www-afpmb.acq.osd.mil) offers information on the various pest control projects on military bases and publications. The Human Dimensions Research Unit (http://www.hdru.cornell.edu) at Cornell University includes the full text of reports done by the unit on human-wildlife conflicts.

State Wildlife Links. State and regional information can be found at the extension service, experiment stations, and university sites. Pages that include wildlife damage information are the Kansas State Wildlife Management Library (http://www.oznet.ksu.edu/library/pub/library/wildlif/wldlfpub.htm) which has an extensive library of bulletins, and information sheets; Mississippi Wildlife Damage Management (http://www.ccs.msstate.edu/anr/wildlife.wildlife/wildlifedamage.html); Missouri Division of Conservation (http://www.state.mo.us/conservation/index.html); the Virginia Department of Agriculture (http://www.state.va.us/~vdacs/opps/opps/nusiance.html) page on Nuisance Birds; and the North Carolina Division of Wildlife Management (http://www.state.nc.us/wildlife/management). The Texas Oral Rabies Vaccination Program (http://www.tdh.state.tx.us/zoonosis/orvp) reports information on the vaccination program and includes the full-text of reports on the project. The Texas Natural Resources Web (http://texnat.tamu.edu has already been mentioned earlier in this article.

International Wildlife. International sites hold a wealth of information on wildlife damage management and pesticide use. The Canadian Wildlife Service (http://www.ec.gc.ca/cws-scf/cwshom_e.html); the Australian Commonwealth Scientific and Research Organization (http://www.dwe.csiro.au/research/progv/progv.htm); and the Vertebrate Biocontrol Cooperative Research Center (http://www.dwe.csiro.au/crcs/vbc) cover information on Australia's vertebrate pest control projects. The Consortium for International Crop Protection (http://www.IPMnet.org) goal is to reduce food-crop losses by pests while also safe-guarding the environment. Information on African wildlife can be found at Wildnet Africa (http://www.wolfe.net/~scat/index.html) and African Wildlife (http://www.wolfe.net/~scat/main.html).

Animal-Related Web Sites

The ultimate animal-related source on the Internet is NETVET: Veterinary Resources & Electronic Zoo (http://netvet.wustl.edu). The authors have done an outstanding job of indexing publications, sites on specific animals, organizations, newsgroups, etc. Sites cover the gamut from pet care to wildlife research on both a national and international scale. Some sites that are of special interest to the wildlife damage control community are: BirdSource (http://birdsource.cornell.edu) and the Cornell Laboratory of Ornithology (http://birds.cornell.org) have links to bird research sites, publications, slide collections, and a library of bird sounds. DuckData (http://www.nwrc.nbs.gov/duckdata/duckdate.html) is a searchable bibliographic data base of North American waterfowl from the Biological Resources Division of U.S. Geological Survey. The Ornithological Council's BIRDNET (nmnhgoph.si.edu/BIRDNET/index.html) and North American Breeding Bird Survey (http://www.mbr.nbs.gov/bbs.html) are invaluable for information on bird migration, surveys, and other information on bird research. Llama Web (www.webcon.com/~degraham/uses/welcome.html) covers everything about llamas including breeding information, show announcements, and a section on guard llamas. DeerNet (http://www.deer.rr.ualberta.ca/about.html) is maintained by the University of Alberta, Canada. It covers the ecology, management, and utilization of hoofed mammals. The International Wolf Center (http://www.wolf.org) is a great source for links to wolf research and management. The World Wide Web Virtual Library on Herptology (http://xtal200.harvard.edu:8000/herp) has links to everything creepy crawlie on the web (Johnson 1997).

Agriculture

Sites related specifically to agriculture on the Internet are numerous. The National Agricultural Library (http://www.nalusda.gov) is a good place to start if you are looking for literature or links to other agriculture related sites. The Agriculture Network Information Center (http://www.agnic.nal.usda.gov) indexes both industry and research sites on agriculture and related industries. The World Wide Web Virtual Library on Agriculture (http://ipmwww.ncsu.edu/cernag/cern.html) has hundreds of links on biological control, agricultural economics, biotechnology, and ag sites around the world. The National Agricultural Statistical Service (http://www.nass.usda.gov) is accessible through the Agriculture Department or Cornell's Mann Library (http://mann77.manlib.cornell.edu/reports.nassr). The Cooperative State Research Education & Extension Service (http://www.reeusda.gov/new/csrees.htm) links to all the state extension service units and contains reports, bulletins, flyers, and other informational material on wildlife control.

Environmental and Life Sciences Sources

General information on the ecology, biology, and related sciences can be found at some of the following sites. Envirolink (http://www.envirolink.org) is an award winning index to environmental groups and sites. The Environmental News Network's (http://www.enn.com) goal is to be the world's premier source of original environmental and science news. Photographs, video, and audio are attached to the text articles and can be downloaded. The World Wide Web Virtual Library (WWW-VL) on the Environment (http://ecosys.drdr.virginia.edu/environment.html); Virtual Library of Ecology, Biodiversity, and the Environment (http://conbio.rice.edu.vl); and WWW-VL Biosciences (http://golgi.harvard.edu/biopages.html) link to reference tools, industry contacts, research and government pages, and hundreds of other related sites (Clark 1997). The Natural Resources Research Information Pages (http://sfbox.vt.edu:10021/Y/yfleung/forlit.html) is a directory to hundreds of environmental research databases, literature, and websites. The List of WWW Sites of Interest to Ecologists (http://www.biol.uregina.ca/liu.bio/Ecology-www.html) is a great list of sources but is hampered by a lack of subject indexing. Infomine: Comprehensive Biological, Agricultural and Medical Internet Resource Collection (http://lib-www.ucr.edu) is a fully indexed and annotated guide to over 1,500 reference sources. My Virtual Reference Desk ENVIRONMENT (http://www.refdesk.com/cgi-bin/refsrch.cgi/search/me?environment) has numerous environmental dictionaries and indexes available for searching. Natural Resources-International Government Agencies (http://sfbox.vt.edu:1002/Y/yfleung/agency.html) indexes natural resource agencies around the world by country or region (Weaver 1997).

Commercial Sites

There are several commercial sites on the Internet that have been used by librarians and researchers to locate wildlife information. Dialog Select (http://dialogselect.krinfo.com) has 250 databases including BIOSIS™ and the Zoological Record™ accessible through an Internet subscription. The search engine is easy to use and copies of articles are available for purchase (O'Leary 1997a). NISC (http://www.nisc.com) now offers access to their CD-ROM products through the Internet on a subscription basis. Wildlife Worldwide™ is touted as the largest index to literature on wild animals, birds, reptiles, and amphibians and is considered a better information source than Dialog's Zoological Record (Chrisman 1996). You can obtain copies of articles you find on the Internet from CARL Corporation's UNCOVER (http://uncweb.carl.org) site. CARL also has an automated alerting service that delivers the table of contents of journals you select to your e-mail box. Users can create subject searches, run them on the database, and then receive weekly alerts of new citations as the database is updated.

There are many "hidden" databases on the Internet that contain information that typical search engines will not find. These sites may require registration before using them like the New York Times (http://www.nytimes.com) or the Thomas Register (http://www.thomasregister.com), a gem of a site for locating product and supplier information. You have to be a detective and go to the specific company or agency site to find these storehouses of information (Notess 1997b).

Industry Links

Locating industry information has become easier as many organizations and commercial companies have created web sites. A few related to wildlife damage management are the American Sheep Industry (http://www.sheepusa.org) and the Cattlemen's Association (http://www.ncanet.org). Wildlife Control Technology Magazine's (http://wctech.com) webpage lists new products, National Wildlife Management Association meeting announcements, and has an index to the articles that have appeared in the magazine.

Animal Rights Groups

Many environmental and animal rights groups have an interest in wildlife damage control and have a presence on the web. The Humane Society of the United States (http://www.hsus.org), Animal Protection Institute (http://www.api4animals.org), the Animal Defense League (http://php.indiana.edu/~adl/adl1.html), Defenders of Wildlife (www.defenders.org), Friends of Animals (http://www.envirolink.org/orgs.foa), Coalition for the Prevention of the Destruction of the Canda Goose (http://www.icu.com/geese/coalition.html), and Fund for Animals (www.fund.org) all have information about their organizations, contact names and telephone numbers, and details about current campaigns. Groups that have a specific interest in predator control are the People for the Ethical Treatment of Animals (http://www.envirolink.org/arrs/peta), the Predator Defense Fund (http://www.envirolink.org/arrs/pdi/index.htm), the Predator Project (http://www.wildrockies.org/predproj), and Sinepau (http://www.smapu.org). Predator Protection (http://www.arkonline.com) focuses on predators in the northwest United States and has videos on bear poaching and fox hunting available for viewing.

Additional sites within the U.S. Government are shown in the list below.

Agriculture Department	www.usda.gov
Bureau of Land Management	www.blm.gov
Environmental Protection Agency	www.epa.gov
Federal Aviation Administration	www.faa.gov
Fish & Wildlife Service	www.fws.gov
Forest Service	www.fs.fed.gov
Library of Congress	Lcweb.loc.gov
National Biological Resources (USS)	www.nbs.gov
National Park Service	www.nps.gov

SUMMARY

The Internet offers a wealth of information that can drown the user if you do not use judgment and skill in searching through the myriad of websites. There are many tools that have been collected by libraries, universities, and other groups to help you find the information you are looking for. You should always use judgment in citing references and only use reputable resources.

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DEVELOPMENT OF AN INTERNET CENTER FOR WILDLIFE DAMAGE MANAGEMENT (html.www.ianr.unl/wildlife)

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ABSTRACT: Information, materials, and services on wildlife damage management are available through educational institutions, agencies, and private industry, but access is highly variable, depending on the location and type of problem that exists. With the development of the worldwide web, electronic information on vertebrate pests has proliferated, but access by direct links or browsers has limitations. The authors have developed a website that will serve as an Internet Center for information on wildlife damage management. It provides links to web-based publications, reference materials, list servers, agency and organization websites, home-study and certification programs, and information and service providers. The Internet Center will significantly increase public awareness and understanding of wildlife damage problems. It will facilitate distribution of information to the public and improve communication among resource providers. Ultimately, the Center will increase implementation of integrated pest management (IPM) practices that will lead to increased economic and environmental benefits.

KEY WORDS: internet, communication, integrated pest management, vertebrate pests, website, wildlife damage management

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INTRODUCTION

Wildlife damage problems are experienced by all segments of society. Row crops, forages, rangeland, fruits, vegetables, ornamentals, and turf are all susceptible to wildlife damage at various stages of development. Agricultural producers lose billions of dollars each year due to crop damage caused by deer, voles, blackbirds, and other wildlife species (Conover et al. 1995). In addition, over 75,000 people are injured annually or become ill in North America due to wildlife-related incidents. For most of these problems, IPM principles can be applied to reduce damage to tolerable levels. Information, materials, and services on wildlife damage management are available through educational institutions, agencies, and private industry, but access is highly variable, depending on the location and type of problem that exists. The worldwide web provides an excellent opportunity to consolidate existing and future information on IPM and wildlife damage management. The authors have developed a Center on the worldwide web (html.www.ianr.unl/wildlife) to facilitate distribution of information and increase adoption of IPM practices. They anticipate that it will become a widely known, one-stop website that facilitates access to up-to-date, comprehensive, and useful information on wildlife damage management. The project is national, if not international, in scope.

The goal of this project is to increase adoption of IPM practices through the development and maintenance of a website on the internet that will centralize access to wildlife damage management information. The measurable objectives include: 1) increase public access (producers, consultants, homeowners) to all internet information on IPM practices associated with wildlife damage management; 2) increase public access to agencies, organizations, consultants, and materials vendors that provide information and assistance on wildlife damage management; and 3) increase communication among resource professionals associated with IPM and wildlife damage management on the internet. It is anticipated that the website will significantly increase producer and public awareness of wildlife damage problems and management techniques.

METHODS

The Internet Center is a website, maintained on a server at the University of Nebraska's Distributed Environments for Active Learning Laboratory. In the boundaryless environment of the worldwide web, investigators, technicians, and collaborators work together from their own home sites to maintain and update the website. Links will be established among the web page and all selected wildlife damage management information on the internet. Examples include extension, state and federal fact sheets, circulars, and guides. Links have been established to websites of USDA-IPM, USDA-Wildlife Services, National Wildlife Research Center, Berryman Institute for Wildlife Damage Management, The Wildlife Society, state wildlife agencies, and private industry consultants and materials vendors. The authors have also linked to the book, "Prevention and Control of Wildlife Damage," and the listserver WDAMAGE, which functions as a communication bulletin board. New information will be scanned and incorporated into the web, including components of wildlife damage conference proceedings, refereed journal publications, and home-study courses. The website will be maintained in the future and new information will be added as it becomes available.

Impacts of the website will be evaluated by two methods. First, an on-line questionnaire will be maintained that will generate information about user knowledge regarding IPM, implementation of IPM practices, pesticide use, land area affected, and money saved. In addition, the number of user contacts associated with information sources, linked websites, and WDAMAGE will be determined annually.

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CLOSING REMARKS — EIGHTEENTH VERTEBRATE PEST CONFERENCE

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As Chair-Elect of the Council, I would like to thank all of those who participated in this 18th Vertebrate Pest Conference here at the Double Tree Hotel, Costa Mesa, California. Thanks to A. Charles Crabb, University of California, for handling all arrangements for this event.

We had a total attendance of 409 from 31 states in the U.S., including attendees from 6 countries outside the U.S. This is the largest attended conference in the last four held, although attendance from foreign countries was down.

Special thanks go to Chair, Rex O. Baker, Cal Poly State University at Pomona, who kept us headed in the right direction and to our Program Co-Chairpersons, W. Paul Gorenzel and Desley A. Whisson, University of California, who did an outstanding job of providing a program with a variety of information. I have attended the conferences since 1976 and there have been tremendous changes since then. We continue to have higher quality papers and diversity with a better mix of theory and application.

We had approximately 15 Exhibitors of Commercial Displays this year arranged through Council Members Greg Giusti and Bob Timm, University of California.

Minoo Madon from the California Department of Health Services, Vector-Borne Disease Section, Ontario, arranged for our field trip through the Los Angeles area, including historical plague sites. Gary Simmons, USDA, APHIS, Wildlife Services, Sacramento, handled publicity in a reliable manner; hence the good attendance. Thanks to Sydni Gillette, University of California, Davis, who once again handled the massive job of registration. Sydni was assisted by Becky Miller, student assistant, and on-site by various Council Members, Terry Salmon, Charlie Crabb, Rex Marsh, Charles Smith, Pierre Gadd, Lew Davis, John O'Brien, John Borrecco, and others we may have forgotten. Continuing Education was handled through PAPA this year. We would also like to thank Gerry Miller, CDFA, for transporting registration materials to the southern California area and arranging for CDFA employees to help run projectors and lights. Thanks to various other individuals from USDA-Health and students and retirees who also helped run projects and other support functions.

The next conference (19th Vertebrate Pest Conference) will be held March 5-9, 2000, at the San Diego Mission Valley Hilton, San Diego, California. Thank you for attending this 18th Vertebrate Pest Conference, and we hope to see you in the year 2000.

CONFERENCE PARTICIPANTS

The number of registered attendees was 409. The participants came from 31 states, the District of Columbia, and from 6 other countries. The wide representation from the United States and countries throughout the world contributed to the success of the Conference by providing a highly knowledgeable and diversified group for the exchange of research progress, new ideas, and information on a wide range of vertebrate pest topics.

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